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Derwent World Patents Index
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Term: L12 and (quadrature or mode)

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Search History

DATE: Monday, November 10, 2003 Printable Copy Create Case

Set Name side by side	Query	Hit Count	Set Name result set
	DB=USPT,PGPB,JPAB,EPAB,DWPI,TDBD; PLUR=YES; OP=ADJ		
L13	L12 and (quadrature or mode)	8	L13
L12	L11 and ((ground$5) with (virtual$4 or middle or central$3 or center$4))	10	L12
L11	L10 and (coupl$6 or decoupl$6 or de-coupl$6 or de-tun$5 or detun$5)	68	L11
L10	L9 and (simultaneous$4 or "at the same time" or symmetr$9)	74	L10
L9	L8 and ((TEM or birdcage or bird-cage or "bird cage" or solenoid$5 or alderman or Grant or saddle or (transverse with electromagnetic with wave) or CRC or (counter adj rotat$6) or helmholtz or surface or local) with (coil or pair or group or "set" or array or plurality))	90	L9
L8	L7 and (cancel$9 or minim$9 or reduc$6 or null$9 or block$5)	152	L8
L7	L6 and (filter$5 or band or high or low or pass or "hp" or "lp" or stop$5)	153	L7
L6	L5 and (individual$3 or isolat$5 or independent$3)	153	L6
L5	L4 and (field-of-view or fov or "field of view")	167	L5
L4	L3 and (virtual$4 or middle or central$3 or center$4)	20621	L4
L3	L2 and (ground$5)	27440	L3
L2	L1 and (coil or ring or ellip$7 or circular$4)	84368	L2
L1	((radio adj frequency) or rf or radio-frequency)	248605	L1

END OF SEARCH HISTORY

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Search Results - Record(s) 1 through 8 of 8 returned.

1. Document ID: US 20020040185 A1

L13: Entry 1 of 8 File: PGPB Apr 4, 2002

PGPUB-DOCUMENT-NUMBER: 20020040185
PGPUB-FILING-TYPE: new
DOCUMENT-IDENTIFIER: US 20020040185 A1

TITLE: Systems and methods for evaluating the urethra and the periurethral tissues

PUBLICATION-DATE: April 4, 2002

INVENTOR-INFORMATION:

NAME	CITY	STATE	COUNTRY	RULE-47
Atalar, Ergin	Columbia	MD	US	
Quick, Harald	Essen-Werden	MD	DE	
Karmarkar, Parag	Elliott City		US	

US-CL-CURRENT: 600/423

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw Desc | Image

2. Document ID: US 6608480 B1

L13: Entry 2 of 8 File: USPT Aug 19, 2003

US-PAT-NO: 6608480
DOCUMENT-IDENTIFIER: US 6608480 B1

TITLE: RF coil for homogeneous quadrature transmit and multiple channel receive

DATE-ISSUED: August 19, 2003

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Weyers; Daniel J.	Wauwatosa	WI		

US-CL-CURRENT: 324/318; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | Claims | KWIC | Draw Desc | Image

3. Document ID: US 6411090 B1

L13: Entry 3 of 8 File: USPT Jun 25, 2002

US-PAT-NO: 6411090
DOCUMENT-IDENTIFIER: US 6411090 B1

TITLE: Magnetic resonance imaging transmit coil

DATE-ISSUED: June 25, 2002

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Boskamp; Eddy B.	Menomonee Falls	WI		

US-CL-CURRENT: 324/318; 324/309, 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
Draw Desc | Image

4. Document ID: US 6177797 B1

L13: Entry 4 of 8 File: USPT Jan 23, 2001

US-PAT-NO: 6177797
DOCUMENT-IDENTIFIER: US 6177797 B1

TITLE: Radio-frequency coil and method for resonance/imaging analysis

DATE-ISSUED: January 23, 2001

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Srinivasan; Ravi	Richmond Heights	OH		

US-CL-CURRENT: 324/318; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
Draw Desc | Image

5. Document ID: US 6150816 A

L13: Entry 5 of 8 File: USPT Nov 21, 2000

US-PAT-NO: 6150816
DOCUMENT-IDENTIFIER: US 6150816 A

TITLE: Radio-frequency coil array for resonance analysis

DATE-ISSUED: November 21, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Srinivasan; Ravi	Richmond Heights	OH		

US-CL-CURRENT: 324/318; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
Draw Desc | Image

6. Document ID: US 6122042 A

L13: Entry 6 of 8 File: USPT Sep 19, 2000

US-PAT-NO: 6122042
DOCUMENT-IDENTIFIER: US 6122042 A

TITLE: Devices and methods for optically identifying characteristics of material objects

DATE-ISSUED: September 19, 2000

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Wunderman; Irwin	Mountain View	CA	94040-3875	
Smith; Adolph E.	Santa Cruz	CA	95060-2345	
Lumba; Vijay K.	San Jose	CA	95148	

US-CL-CURRENT: 356/73; 356/343

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
Draw Desc | Image

7. Document ID: US 5999000 A

L13: Entry 7 of 8 File: USPT Dec 7, 1999

US-PAT-NO: 5999000
DOCUMENT-IDENTIFIER: US 5999000 A

TITLE: Radio-frequency coil and method for resonance imaging/analysis

DATE-ISSUED: December 7, 1999

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Srinivasan; Ravi	Richmond Heights	OH		

US-CL-CURRENT: 324/318; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KWIC
Draw Desc | Image

8. Document ID: US 5777474 A

L13: Entry 8 of 8 File: USPT Jul 7, 1998

US-PAT-NO: 5777474

DOCUMENT-IDENTIFIER: US 5777474 A

TITLE: Radio-frequency coil and method for resonance imaging/analysis

DATE-ISSUED: July 7, 1998

INVENTOR-INFORMATION:

NAME	CITY	STATE	ZIP CODE	COUNTRY
Srinivasan; Ravi	Richmond Heights	OH		

US-CL-CURRENT: 324/318; 324/322

Full | Title | Citation | Front | Review | Classification | Date | Reference | Sequences | Attachments | KMC
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Term	Documents
QUADRATURE	53725
QUADRATURES	92
MODE	1151482
MODES	320645
(12 AND (QUADRATURE OR MODE)).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	8
(L12 AND (QUADRATURE OR MODE)).USPT,PGPB,JPAB,EPAB,DWPI,TDBD.	8

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Previous Page Next Page

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L13: Entry 4 of 8 File: USPT Jan 23, 2001

DOCUMENT-IDENTIFIER: US 6177797 B1
TITLE: Radio-frequency coil and method for resonance/imaging analysis

Abstract Text (1):
An RF coil with high signal-to-noise (S/N) and B.sub.1 homogeneity over the volume originating from the arctic arch and extending to the top of the head, which is highly desirable for quantitative (anatomical, vascular and functional) studies in-vivo. The coil is suitable for use in performing multiple studies and reducing scan time without patient repositioning. Moreover, the coil is capable of imaging in different operating modes. A split-top design is used to ease patient access.

Brief Summary Text (2):
The present invention relates generally to resonance systems, such as magnetic resonance imaging (MRI) systems, and more particularly to a radio-frequency (RF) coil and method for use in such systems.

Brief Summary Text (4):
In MRI systems or nuclear magnetic resonance (NMR) systems, a static magnetic field B.sub.0 is applied to the body under investigation to define an equilibrium axis of magnetic alignment in the region of the body under examination. An RF field is then applied in the region being examined in a direction orthogonal to the static B.sub.0 field direction, to excite magnetic resonance in the region, and resulting RF signals are detected and processed. Generally, the resulting RF signals are detected by RF coil arrangements placed close to the body. See for example, U.S. Pat. No. 4,411,270 to Damadian and U.S. Pat. No. 4,793,356 to Misic et al. Typically such RF coils are either surface type coils or volume type coils, depending on the particular application. Normally separate RF coils are used for excitation and detection, but the same coil or array of coils may be used for both purposes. For multiple surface RF coils for use in NMR, see U.S. Pat. No. 4,825,162 to Roemer, et al., and for multiple volume coils for use in NMR, see U.S. Pat. No. 5,258,717 to Misic, et al.

Brief Summary Text (5):
A quadrature type coil was introduced by Hayes in 1985 to the NMR community. This coil was readily adopted by scientists and engineers in the NMR community for several volume applications (e.g., body, head, knee, wrist). The coil provided a 41% improvement in signal-to-noise ratio (S/N), a reduction of transmit power by a factor of two and a high degree of B.sub.1 homogeneity over the imaging field-of-view (FOV). The principal quadrature mode of this coil has two linear modes, oriented orthogonal to one another. Additional details regarding such a coil design are found in U.S. Pat. No. 4,783,641 to Hayes, et al.

Brief Summary Text (6):
The recent introduction of array coils to NMR has led to commercially available CTL coils for entire spine imaging, and flexible body arrays for torso imaging. These multichannel coils also significantly help reduce scan times. Should there be any brain trauma in conjunction with the c-spine injuries most common in automobile accidents, this necessitates two studies to be performed. Currently, two coils and more particularly two patient settings are required to perform a combined head and neck study (see, e.g., N. Krause, et al. " Quadrature-Head Coil and Helmholtz-Type Neck Coil--an Optimized RF-Antenna-Pair for Imaging Head, Neck and C Spine at 1.0T and 1.5T", SMRM, 7th Annual Meeting, San Francisco, Book of Abstracts, page 845,

1988). A routine MR study takes approximately 45 minutes, including the patient placement. Thus a combined head and neck study approximates an hour-and-half, and requires that the patient be moved between studies for coil replacement. This is uncomfortable especially for claustrophobic patients in general. In addition, prolonged scan times make the contrast-enhanced studies even more difficult to obtain.

Brief Summary Text (7):
In such cases of cranio-spinal trauma, a head and neck coil will help obtain important clinical information without compromising image quality over extended FOV's. This will also be true in the cases of vascular imaging of the carotids originating from the arctic arch and extending to the circle of willis, and for oncological imaging of the head and neck tumors, without moving the patient. A head and neck array will help reduce patient discomfort while reducing the scan times and increase the patient throughput by up to a factor of two in a MR scanner.

Brief Summary Text (8):
Array type coil designs have been disclosed in the prior art. For example, two birdcage resonators (one for the head, another for the neck) have been overlapped for minimum mutual inductance (see FIG. 1). The neck birdcage 10 was asymmetric and had cutouts to accommodate the shoulders of patients. When this asymmetric birdcage was overlapped to the symmetric head birdcage 12, the individual modes were affected differently. Such an array design is discussed in C. Leussler, "Optimized Birdcage Resonators for Simultaneous MI of Head and Neck", SMRM 12th Annual Meeting, New York, Book of Abstracts, page 1349, 1993.

Brief Summary Text (9):
Referring still to FIG. 1, since the anatomy introduced in the two coils was different, the individual linear modes of the two coils 10, 12 were perturbed in different ways, causing the linear modes to misalign and reduce the isolation between modes in a coil. This in turn affected the isolation with the linear mode in the neighboring coil, thus affecting the isolation between coils in the array. Thus, the optimum overlap for one linear mode was not optimum for the second linear mode of the same coil. Moreover, poor isolation between coils affected the coil matching which in turn affected the alignment and isolation of modes in the individual birdcage which in turn affected the isolation between coils in the array. Therefore, optimization of this coil design (tuning, matching, isolation, alignment of modes of coils in the array) was very complex, iterative and often time consuming, thus making the manufacturing process extremely difficult. In addition, this coil design presented added claustrophobia to patients and therefore was not acceptable for clinical imaging.

Brief Summary Text (10):
FIG. 2 illustrates another array design which included a birdcage coil 14 for the head, and a distributed type quadrature planar pair 16 for the neck. (See, e.g., Srinivasan, R, et al. "A Multi-Modal, Split-Top Head and Neck Vascular Array for MRI", SMR 3rd Scientific Meeting, Nice, France, Book of Abstracts, page 977, 1995; and U.S. Pat. No. 5,543,711to Srinivasan, et al.). The neck coils were overlapped with the head birdcage 14 independent of the other. This was possible, because the neck coils were intrinsically isolated from one another. Although this design was more elegant than the above two coil designs, the sensitivity of the coil in the N mode (neck mode) was under that of the commercially available, adjustable whole-volume neck coil. The characterization of this deficit was difficult because of the dilemma of comparing surface type coil S/N to that of the helmholtz type volume coil. In any case, identical clinical scans obtained from the same volunteers clearly showed such a deficit.

Brief Summary Text (11):
The surface coil design emphasized signals from surfaces close to the coil. Therefore, shimming with this coil was difficult and fat suppression was a challenge. The axial neck images displayed un-even signal intensities in the vertical direction. Also, extended FOV sagittal/coronal images of the head and neck displayed a discontinuity at the coil overlap which affected the overall appearance of the image. This also made the windowing of the images difficult. In order to correct for the uneven signal intensities, a new image intensity correction software

was employed (based on the RF coil profile), which slowed the image combination process. In addition, the linear modes of the coil were interfaced to the multiple channels of the MR system, which further reduced the image reconstruction process.

Brief Summary Text (12):
In view of the aforementioned shortcomings associated with existing coil designs, there is a strong need in the art for a quadrature array design that provides a high S/N and uniform coverage over the head and neck areas, and which obviates the need for two separate coils and the additional image correction software.

Brief Summary Text (14):
The present invention provides an RF coil with high signal-to-noise (S/N) and B.sub.1 homogeneity over the volume originating from the arctic arch and extending to the top of the head, which is highly desirable for quantitative (anatomical, vascular and functional) studies in-vivo. The coil is suitable for use in performing multiple studies and reducing scan time without patient repositioning. Moreover, the coil is capable of imaging in different operating modes. A split-top design is used to ease patient access.

Brief Summary Text (15):
The present invention provides high image quality (image S/N and homogeneity) by introducing a multichannel RF coil array with a unique combination of quadrature volume and surface coils. Coil-to-coil decoupling electronics are introduced that facilitate multiple mode operation without compromising S/N. These features help provide head and neck imaging over the extended FOV in one clinical setting, without significantly compromising image quality.

Brief Summary Text (16):
According to a preferred embodiment, an RF coil in accordance with the present invention has has two counter-rotating, helmholtz pairs arranged orthogonally to constitute a quadrature pair forming a first coil, a quadrature volume birdcage forming a second coil, and a modified spoke type quadrature surface coil representing a third coil. Furthermore, coil-to-coil decoupling electronics are provided. All the coils are overlapped to maintain a minimum mutual inductance and hence minimal cross-talk. The first coil coverage originates from the arctic arch and extends to the brain stem. The second and third coils permit a combined coverage that originates from the c-spine and extends to the top of the head. Depending on the operating mode, individual coils in the array can be turned OFF or ON by a programmable transmit/receive (T/R) driver in the MI system. Passive coil-to-coil decoupling electronics that include coaxial cable traps serve to (1) break any closed ground loops during RF transmit; (2) minimize any residual cross-talk between coils; and (3) permit efficient multiple mode operation.

Brief Summary Text (17):
In general, the improved S/N and uniform coverage over the head and neck as provided by the RF coil of the present invention will translate into improved image quality, enhanced diagnostic accuracy, and increased patient throughput. The coil provides broad use in examinations of the brain, skull, face, neck, cervical spine, and blood vessels in patients with craniospinal traumatic injuries, stroke and other cerebrovascular disorders, and head and neck cancer, etc.

Brief Summary Text (18):
According to one particular aspect of the invention, a radio-frequency (RF) coil apparatus for resonance imaging/analysis is provided. The RF coil apparatus includes a first quadrature volume coil; a second quadrature volume coil at least partially overlapping the first quadrature volume coil; and a quadrature surface coil at least partially overlapping the second quadrature volume coil.

Brief Summary Text (19):
According to another aspect of the invention, a radio-frequency (RF) coil apparatus for resonance imaging/analysis is provided. The RF coil includes an RF volume coil sensitive to RF signals produced during resonance imaging/analysis; and an RF surface coil, also sensitive to the RF signals, physically positioned relative to the RF volume coil to share a common axis and to produce an overlap of the magnetic B fields of the respective coils at a frequency of the RF signals.

Brief Summary Text (20):
According to yet another aspect of the invention, a radio-frequency (RF) coil apparatus for resonance imaging/analysis is provided which includes a first quadrature volume coil; a second quadrature volume coil at least partially overlapping the first quadrature volume coil; a quadrature surface coil at least partially overlapping the second quadrature volume coil; and coil -to-coil decoupling circuitry for preventing closed ground loops.

Drawing Description Text (2):
FIG. 1 is a perspective view of a conventional two birdcage type RF coil, one birdcage resonator used for the head and the other birdcage resonator used for the neck;

Drawing Description Text (3):
FIG. 2 is a schematic view of a conventional RF coil which combines a birdcage coil for the head and a distributed type quadrature planar pair for the neck;

Drawing Description Text (4):
FIG. 3 is a schematic view of an RF coil having a quadrature pair coil, a birdcage coil, and modified-spoke type quadrature surface coil in accordance with a preferred embodiment of the present invention;

Drawing Description Text (5):
FIGS. 4a and 4b represent a normalized coronal contour @Y=0 and normalized sagittal contour @X=0, respectively, for an RF coil having the exemplary dimensions provided herein in accordance with the present invention;

Drawing Description Text (6):
FIG. 5 illustrates the preferred mode orientations in accordance with the present invention;

Drawing Description Text (7):
FIG. 6 is a planar schematic illustration of the neck coil in accordance with the preferred embodiment of the present invention;

Drawing Description Text (8):
FIG. 7 is a schematic illustration representing the orientation of the loops within the neck coil of FIG. 6 in accordance with the present invention;

Drawing Description Text (9):
FIG. 8 is a schematic illustration of the birdcage coil in accordance with the preferred embodiment of the present invention;

Drawing Description Text (10):
FIG. 9a of a schematic diagram of a quadrature surface coil symmetrically overlapped with a conventional birdcage coil with reduced usable imaging field of view;

Drawing Description Text (11):
FIG. 9b is a schematic diagram of a modified quadrature surface coil asymmetrically overlapped with a birdcage coil in accordance with the preferred embodiment of the present invention;

Drawing Description Text (12):
FIG. 10 is a detailed schematic illustration of the modified quadrature surface coil of FIG. 9b in accordance with the present invention;

Drawing Description Text (13):
FIG. 11a is a detailed schematic illustration of the modified quadrature surface coil of FIG. 9b including coupling circuitry in accordance with the present invention;

Drawing Description Text (14):
FIG. 11b is a schematic diagram of the decoupling circuitry in accordance with the preferred embodiment of the present invention;

Drawing Description Text (15):
FIG. 12 is a normalized plot of the B field along the coil axis in accordance with the present invention; and

Detailed Description Text (3):
Referring now to FIG. 3, an RF coil array (herein referred to as an " RF coil") in accordance with a preferred embodiment of the present invention is generally designated 20. The RF coil 20 is designed as a split-top array having two counter-rotating, helmholtz pairs 22a, 22b arranged orthogonally to constitute a quadrature pair designated as coil #1. In addition, the coil 20 includes a quadrature volume birdcage (coil #2) and a modified spoke type quadrature surface coil (coil #3), and includes coil-to-coil decoupling electronics. Only the coil outlines are shown , for brevity. All the coils are overlapped to maintain a minimum mutual inductance and hence minimal cross-talk. Coil #1 coverage originates from the arctic arch and extends to the brain stem. Coil #2 and coil #3 permit a combined coverage that originates from the c-spine and extends to the top of the head. Coils #1-#3 provide, as inputs/outputs, signals at terminals labeled CH1--CH3, respectively. The shaded areas include the preamplifiers 26, and coil-to-coil decoupling electronics 28 including the coil grounding . Low-noise preamplifiers 26 (NF<0.55 dB) are included in every channel CH1--CH3 to maintain high S/N. Passive coil-to-coil decoupling electronics that include the coaxial cable traps 28 serve three main functions, namely to (1) break any closed ground loops during RF transmit; (2) minimize any residual cross-talk between coils; and (3) permit an efficient multiple mode operation. A guard ring 30 serves as a common ground for the entire array.

Detailed Description Text (4):
As is discussed in greater detail below, the coil 20 represents a unique combination of several quadrature volume and surface coils . The coil 20 combines a modified quadrature surface coil design with an asymmetric overlap of the modified surface coil to the volume birdcage and unique coil-to-coil decoupling electronics.

Detailed Description Text (5):
The clinical features of the coil 20 are found in its multiple mode operation, viz., (1) head only studies H; (2) volume neck or c-spine studies N; and (3) extended FOV head and neck studies H&N. Depending on the operating mode, individual coils (coils #1-#3) in the array 20 can be turned OFF or ON by the programmable Transmit/Receive (T/R) driver in the MRI system. This array coil will be interfaced to a Picker 1.5T Edge Multichannel MRI system which is commercially available from Picker International, Inc., Highland Heights, Ohio, U.S.A.

Detailed Description Text (6):
By selectively enabling/disabling the coupling/decoupling circuitry in the respective coils, each of the coils #1-#3 can be selectively made resonant (ON) or non-resonant (OFF). Table 1 shows the status of each of the coils #1-#3 for the respective operating modes. Each of the coils #1-#3 is described in detail below.

Detailed Description Text (8):
According to one specific example, coil #2 was configured as a 16 leg birdcage which was 28 cm in diameter and 28 cm long. The modified quadrature surface coil #3 was 22.5 cm in diameter, 2 cm long with 8 spokes, a .sigma. of 0.4 and a VG1, VG2 diameter of 4.0 cm. The overlap between coils #2 and #3 was 4.0 cm. Loop I (FIGS. 6 and 7) in the neck coil (coil #1) was 24 cm long, 14 cm wide at the straight segment, and maintained a 90.degree. arc. This arc began @10.degree. and extended to 100.degree.. The diameter of the arc was 23 cm, whereas the straight segments at the chest traversed on a horizontal plane located at 14 cm along the vertical axis. All remaining loops maintained identical dimensions.

Detailed Description Text (9):
Finally, using the dimensions of the head coils (coils #2, #3) and the neck coil (coil #1) mentioned above and setting the overlap between coils #1 and #2 to 2.5 cm, B field contours were generated. Here the contours were normalized to a point along the dotted line of the H&N mode of FIG. 3. Extended coronal and sagittal contours over a 60 cm FOV are shown in FIGS. 4a and 4b , respectively. It is to be noted that

over a 38 cm FOV, the contour lines vary from 1.2 to 0.7, indicating that there is a 40% change in signal intensity. It is noted that much of the neck anatomy of interest (c-spine) is either below or (arctic arch) much above the central line and will lay in or near the 1.2 contour line. However for a smaller patient, the arch and the neck may lay around the 1.0 contour line. It is further noted that in the preferred embodiment the anterior neck segments will be fixed to reduce the mechanical complexity of an already complex design. The signal intensity of the neck coil (coil #1) may be improved by adding a birdcage instead of a cross -helmholtz design. In this case, the coil will become extremely claustraphobic with the additional technical disadvantage of the coil optimization as mentioned in the prior art section.

Detailed Description Text (10):
It is also noted that the homogeneity significantly improved in the neck region in the H&N mode, when compared to the N mode. In doing so, the homogeneity over the entire brain inside the head coil virtually remained the same. And the areas at the coil overlap, where both the head coil (coil #2) and the neck coil (coil #1) dropped in signal intensity in their respective modes, now gained significantly in the H&N mode. This is specially useful for detecting the tumors located at the skull base. Furthermore, it is noted that in addition to imaging the head or the neck and the combined coverage of the head and neck, this coil 20 will assist in imaging the skull base tumors, the brachial plexus and in the MR angiography of the left and right sub-clavian arteries originating from the arctic arch.

Detailed Description Text (11):
Coil Mode Orientation:

Detailed Description Text (12):
Referring to FIG. 5, the preferred mode orientations for coils #1, #2 and #3 are shown. The individual linear modes a1, a2 and b1, b2 and c1, c2 of the three respective coils, in the proposed array 20, will be tuned and matched to 50 ohms at the NMR frequency. Individual coil linear ports will be summed by separate quadrature hybrids prior to the corresponding preamplifiers. The three coils will be actively decoupled during whole-body RF transmit. Although this will achieve an approximate -25 dB of isolation per coil at the NMR frequency, additional series-shunt pin-diode protection (D1, D2) circuits introduced will present another -45 dB of isolation between the coil and the preamplifier in every channel. A forward biased D1 will shunt any RF present in the signal conductor to ground during body RF transmit, while D2 is reverse biased. During receive D2 is forward biased and D1 will be reverse biased, to let all the NMR signals pass through the corresponding preamplifiers. This diode network along with the coil active decoupling will drastically reduce the amount of RF seen at the input of every amplifier. This will ensure a safe preamp operation (preamplifier input maximum is 20 dBm). Individual preamp outputs will then be channelled to the system for further amplification.

Detailed Description Text (13):
Neck Coil:

Detailed Description Text (14):
A planar schematic of the cross -helmholtz type, quadrature neck coil (coil #1) is shown in FIG. 6. The quadrature neck coil (coil #1) consists of four loops I, II, III and IV, respectively. Loops I and III (22a) and loops 11and IV (22b) are coupled to form a2 and a1 modes, respectively. Modes a1 and a2 form a quadrature pair. Loops I and IlIl are diagonally opposite to one another and oriented at right angles to loops II and IV, respectively. Loops I and II and loops III and IV are overlapped to maintain minimum mutual inductance and hence minimal cross-talk. Their configuration is depicted in FIG. 7.

Detailed Description Text (15):
Loops I and III mutually coupled to one another will give rise to two modes, one that is in-phase and another that is out-of-phase. That is, the two loops mutually coupled will give rise to a counter-rotating and a co-rotating mode, respectively. Since the two loops are placed opposite to one another, the B field generated by the counter-rotating currents in the two opposite loops will add between the region

between the two coils. Whereas the co-rotating currents in the two loops will result in a almost linear B field gradient, which is not desired for homogeneous imaging. This B field gradient may however be used for rotating frame experiments, where a RF gradient is desired. However, for homogeneous imaging, the counter-rotating mode is sought and is therefore the linear mode of interest. This however will depend on how the two loops are hard-wired. With the convention shown, the counter-rotating mode will provide a homogeneous field at the coil center.

Detailed Description Text (16):
Loop III may be broken with four similar value capacitors, 4C in value. One 4C value capacitor may further be broken in to two capacitors 8C in value. The center point of the two 8C value capacitors which happens to be a virtual point ground will be forced to real ground. This will prevent any currents to flow on the shields of coaxial cables and will obviate the need for cable traps and such mechanisms to break the ground loops. The coil will then be matched with Cm to 50 ohms. Loop IV will be identically matched to 50 ohms. If the isolation between the I, III pair and the II, IV pair is not satisfactory (<-20 dB), then the additional isolation network 44 shown may be used to further isolate the individual linear modes. Typical values for the L-C pair in the isolation circuit for 64 MHz are 124 nH and 50 pF, respectively. The capacitor value may be increased or decreased to present a capacitive or an inductive effect. This circuit has been used in many RF coil array designs and have isolated coils to less than -20 dB, on a routine basis.

Detailed Description Text (17):
A quadrature hybrid 46 discussed in the birdcage section will be used for this coil as well. A similar diode network 48 discussed above in FIG. 5 will be used for preamp protection. Also, a low-noise preamp 26 (NF<0.55 dB) will be incorporated in the circuitry prior to the system amplification. The helmholtz loops will be actively decoupled with active pin diodes. A parallel trap will be created across the 4C value capacitors by using a suitable inductor value, to resonate at the NMR frequency. This parallel trap will present a high impedance to the circulating RF currents and thus behave like an open circuit during body RF transmit. However during receive, the diodes will be reverse biased thus opening the decoupling circuit and the entire coil will be resonant at the NMR frequency as shown in FIG. 6. One such active decoupling circuit is described in the modified surface coil section.

Detailed Description Text (18):
High-Pass Birdcage Coil :

Detailed Description Text (19):
A planar schematic of an exemplary birdcage coil (coil #2) is shown in FIG. 8. In such exemplary embodiment, the birdcage coil #2 is a 16 leg high-pass birdcage. Here the end rings are broken with sixteen similar value capacitors C1. This coil has eight degenerate modes, of interest is the principal quadrature mode. Balanced matching to the individual ports is accomplished with two C2 capacitors across C1. These are then followed by a criss-cross type 50 ohm balun network (L1-C3, L1 is 124 nH, C3 is 50 pF), needed to transform to an unbalanced match prior to the analog quadrature hybrid. The fourth ports of these baluns are tied to a common ground. Although a standard Wilkinson design may be used for the hybrid, a two element (L2-C4, L2 is 124 nH, C4 is 50 pF) hybrid is proposed for simplicity. If S.sub.1, S.sub.2 denote the signals from the two linear ports and S denotes the signal output, then the mathematical expression for the combination is: ##EQU1##

Detailed Description Text (20):
Since the signals are equal in magnitude and orthogonal in phase, setting .alpha. to 90.degree. will yield a 41% improvement in quadrature S/N. It is noted that the individual linear modes of the birdcage (coil #2) will be aligned to the preferred mode orientations of FIG. 5. This will ensure a balanced head loading of the two linear ports with similar Q values and sample noise contributions. One C1 capacitor in each of the 16 meshes of the birdcage (coil #2) will be decoupled with a pin diode and a suitable inductor as described in the above section.

Detailed Description Text (21):
Modified Quadrature Surface Coil :

Detailed Description Text (22):
The modified quadrature surface coil (coil #3) is of particular importance. Normally, a planar linear or quadrature surface coil will exhibit identical B field distributions on either side of the coil. For this coil to be overlapped with a conventional birdcage, the suitable position where minimal cross-talk was achieved would be at the central virtual ground plane of the birdcage (see FIG. 9a). But since the head was only partially covered by this assembly, this resulted in a markedly reduced usable imaging FOV. This was unacceptable.

Detailed Description Text (23):
However, when the profile of the surface coil was modified from one side to the other, this facilitated an asymmetric overlap of the coils (see FIG. 9b). That is, the surface coil was allowed to be placed toward one end ring of the birdcage and the coils were still isolated from one another. The surface coil placement was mandated by its asymmetric B field profile on either side of the coil. Such a prototype has been built by the inventor, and confirmed the overlap with the conventional head coil and have obtained S/N data from phantoms. Volunteer images clearly displayed high S/N toward the top of the head. Further details may be found in R. Srinivasan, "S/N Improvement in a Conventional Head Coil Toward Top of the Head", submitted to 5th ISMRM, Vancouver, British Columbia, 1997. This coil design presents an elegant solution to increasing the S/N toward the top of the head without compromising image quality. Details regarding the coil #3 are found in U.S. patent application Ser. No. 08/745,893 by Srinivasan, the entire disclosure of which is incorporated herein by reference.

Detailed Description Text (24):
A modified, quadrature surface coil (coil #3) is shown in FIG. 10. This consists of a RF coil primary 50, a RF coil secondary 52 and coupling impedances Cc that couple the primary 50 to the secondary 50. Here, the primary 50 and the secondary 52 are coupled mutually through space and electrically through Cc. The primary 50 and secondary 50 are also coupled to the meshes that connect the primary and the secondary. For such a periodic structure (primary mesh "a", secondary mesh "b" and the corresponding mesh connecting the primary and secondary "c"), eigenmode solutions correspond to currents that are in-phase by a factor of e.sup.-j.beta. from mesh to mesh, with the requirement that the total phase change N.beta. be a multiple of 2.pi., thus N.beta.=2.pi.k for the k.sup.th mode. By considering standing wave solutions around the ring structure, one may write that I.sub.n =I.sub.1 cos 2.pi.k(n-1)/N, for the n.sup.th mesh. Kirchoff's mesh equations can be written for "a", "b" and "c" meshes and can be solved using the similar approach of reference 10, thus arriving at the following solution for the k.sup.th order mode; ##EQU2##

Detailed Description Text (25):
Here Mac and Lcc will have terms similar to that of Mba and Laa, respectively. N is the total number of meshes, and .omega..sub.ak.sup.2, .omega..sub.bk.sup.2 and (.omega..sub.ck.sup.2 are frequency squared for isolated structures "a", "b" and "c", respectively. Should structures "a" and "b" be only mutually coupled, that is, should coupling impedances be open, then equation 3 will reduce to ##EQU3##

Detailed Description Text (26):
Self and mutual inductances can be computed using computer models and using Neumann formulae (see, e.g., Plonsey, R. And R. E. Collin. "Principles and Applications of Electromagnetic Fields". McGraw Hill Book Company, New York, page 275-276, 1961), or can be measured using the tedious method of Tropp (see, e.g., J. Tropp. "Mutual Inductance in the Birdcage Resonator", SMR 12th Annual Meeting, August 14-20, New York, page 1347, 1993). The inventor has used the former method and predicted frequency modes for the coupled dome resonators to within 2% of the measured data (see, e.g., Srinivasan. R, et al, "A Comprehensive Analysis for Estimating Modes in Coupled Resonators", SMR 4th Annual Meeting, New York, April 27-May 3, page 1425, 1996). However, for simpler circuits, Tropp's method may prove to be efficient and may be used to compare the results from the computer simulations.

Detailed Description Text (27):
A question which remains is how to compute the secondary currents. This may be

accomplished by setting I.sub.b =.sigma.I.sub.a, in the Kirchoff's equations for mesh currents, before solving for .omega..sub.k. A simpler alternative is to populate the coil with known value capacitors and measure the mode frequencies of the individual circuits and the entire coil. The mutual inductances may be calculated or measured as previously described. Once this is accomplished, precise capacitor values and hence .sigma. can be computed using this data and the equations provided, to resonate the coil at the NMR frequency.

Detailed Description Text (28):
In the above-discussed prototype coil, the RF coil primary was inductively coupled to the RF coil secondary. The RF coil secondary produced an inductive or a capacitive effect depending on its resonance frequency. That is, if the RF coil secondary was tuned to a frequency higher than the NMR frequency then it produced a capacitive effect on the RF coil primary. Here, the currents in the RF coil primary and the secondary were in-phase and there was little or no shielding.

Detailed Description Text (29):
However, when the RF coil secondary was tuned to a lower frequency, then it produced an inductive effect. This effect depended on the isolated frequency of the RF coil secondary. Closer the isolated frequency of the RF coil secondary to the NMR frequency, more was the inductive effect and greater were the current fractions on the RF coil secondary. However, the currents were out-of-phase with respect to the RF coil primary which resulted in shielding. This provided an asymmetric B field profile along the coil axis, which allowed an asymmetric overlap with the birdcage. Note this asymmetric B field profile, mandated its overlap with the birdcage.

Detailed Description Text (30):
A planar schematic of the modified surface coil including the coupling are shown in FIG. 11a. Each spoke of the primary RF coil was split with two C1 capacitors, whereas the secondary was split by C5 and C6. L1 is the self inductance for the primary and the secondary spoke circuit. The primary and secondary were bridged with coupling capacitors C3. Trimmer capacitors C2 were utilized for fine tuning the NMR coil. The coil was coupled at two places 90.degree. apart, and across C1 in spokes a and c, respectively. The matching capacitors utilized were C4. In this design, VG1 and VG2 points were shorted and served as a guide to the coupling coaxial cables exiting the RF coil. The symmetry of this coil design forced these points to be at a virtual ground potential. Exiting the coil at these points eliminated any currents on the shields of the coaxial cables and prevented spurious cable resonances.

Detailed Description Text (31):
The active decoupling circuitry of one secondary and primary spoke are shown in FIG. 11b. During RF transmit, D1 was turned ON and the parallel tank of C2-L5 presented a high impedance to the circulating currents. Similarly, the C1-L3 parallel tank presented a high impedance to the circulating currents in the primary RF coil. Please note, the entire coil was actively decoupled as shown here. Thus this coil was transparent to the whole-body uniform transmit field. However during receive, the pin diodes D1 and D2 were reversed biased and the entire coil was resonant as shown in FIG. 11a.

Detailed Description Text (32):
FIG. 12 is a simulation for the B field along the axis for coil #3 of the proposed design. This coil was 25.4 cm in diameter, had 8 spokes, a VG point diameter of 1.75 cm and the primary and the secondary were separated by 2.0 cm. The .sigma. values used were 0.0, 0.2 and 0.4, respectively. As seen, the .sigma. value of 0.4 presented a highly asymmetric profile on either side of the coil, without significantly compromising signal intensity over the imaging FOV. This can be seen by comparing this profile with the profile where .sigma. is 0.

Detailed Description Text (33):
The inventor has built and system tested a 8 spoke prototype, 23 cm in diameter, a VG of 2.0 cm and a .sigma. of 0.4 (C1, C2, C3, C4, C5, C6 values were 82 pF, 1-23 pF, 0 pF, 117 nH, 100 pF, 1000 pF, respectively). The inventor also overlapped this coil to a conventional head birdcage (30 cm dia, 30 cm long), and obtained high S/N data toward the top of the head. For more details, please refer to the abstract submitted to the 5th ISMRM (R. Srinivasan, "S/N Improvement in a Conventional Head

Coil Toward Top of the Head", submited to 5th ISMRM, Vancouver, British Columbia, 1997 . . . , discussed supra).

Detailed Description Text (34):
Coil Overlap:

Detailed Description Text (35):
Construction according to the preferred embodiment is as follows. Coils #1 and #2 will be nominally overlapped to achieve minimal cross talk. Then coil #1 will be removed and a nominal overlap will be achieved between coils #2 and #3. If this overlap is greater than 4.0 cm then coil #3 will be redesigned to attain this overlap. Coil #1will be re-introduced and the isolation between coils #2 and #3 will be remeasured. If this isolation changed dramatically, then it means coils #1 and #3 are interacting. Field plots and images obtained from the quadrature surface coil prototype reveal that the field falls off very rapidly along the coil axis. Hence, little or no cross-talk between coils #1 and #3 is anticipated.

Detailed Description Text (36):
In all cases, an isolation of at least -20 dB will be achieved between coils in the array (a -20 dB isolation between two coils with equal contribution over a common volume reduces the S/N to about 1% which is tolerable in most circumstances, whereas a -6 dB gives rise to about a 10% loss, which is not tolerable). Therefore, a -20 dB was chosen as a reasonable number for a minimum achievable isolation between coils in the array. Please refer to the article by Tropp, J. and K. Derby, "The Loss of Signal to Noise Due to Imperfect Isolation Between Channels of a Quadrature Nuclear Magnetic Resonance Probe", Review of Science Instrumentation 62(11), pages 2646-2653, November 1991 for details regarding this topic.

Detailed Description Text (37):
Coil-to-Coil Decoupling :

Detailed Description Text (38):
In any RF coil array, cable routing is an important factor. An efficient cable routing will lead to an optimal coil design. Should the coaxial cables traverse close to the RF coil, design efforts must be made to maintain cross-talk between neighboring coils to a minimum, and little or no currents be present on the ground shields of the coax when exiting the coil assembly. Should one fail to achieve the former, optimization (tuning, matching and isolation between modes in the quadrature coil and between modes in the neighboring coils) of this coil assembly will be almost impossible. Should one fail to achieve the latter, the coaxial cables will present spurious resonances and will shift the coil frequencies depending on the coil location inside the magnet bore. The shields of these cables will also pick up RF from the whole-body coil during RF transmit. This will affect the transmit field in the imaging FOV and will produce undesirable image artifacts. To substantially minimize these problems and to easily optimize the coils in the array, the use of coil-to-coil decoupling electronics is necessitated.

Detailed Description Text (39):
For the proposed design, the coil-to-coil decoupling electronics consists of passive cable traps and a guard ring. The coaxial cable traps tuned close to the NMR frequency will serve three major functions;

Detailed Description Text (40):
1. The main function was to present a high impedance (Z) for currents flowing on the shields of the cables during RF transmit, there by preventing the formulation of closed ground loops inside the magnet bore.

Detailed Description Text (41):
2. The second function of these bidirectional traps were to present a high impedance to currents induced on both sides of the trap and to isolate one side from another.

Detailed Description Text (42):
3. The third function of these traps were to minimize the cross-talk between the coils in the array where the cable traversed.

Detailed Description Text (43):
One preferred design for the passive coil-to-coil decoupling electronics is illustrated in FIG. 3. This consists of shielded coaxial cable traps 28 for coil #1 and #3 and the guard ring 30 of coil #2. The posterior trap is strategically located under coil #1 and #2 overlap. This was to isolate the currents on the shield exposed to coil #1 to the currents induced on the shield exposed to coil #2. Whereas, for the superior trap the function was slightly different. Should coil #2 see the coaxial cable exiting coil #3, currents will be induced in the cable shield. The main function for this superior trap was to reduce this effect to a minimum before shorting the cable shield to the guard ring. The need for this superior trap is yet to be determined. The coaxial traps will be tuned with fixed value capacitors and fine tuned with variable capacitors to the NMR frequency. Due to close proximity, the traps will be shielded to isolate from the coils in the array and from the whole-body coil during RF transmit and to reduce the radiation from the shields of the straight segments of the coaxial cable.

Detailed Description Text (44):
The guard ring 30 serves a major function of providing a ground path for the several coaxial cables. This guard ring will be broken with large value RF shorting capacitors to reduce any gradient induced eddy currents, while letting the RF currents to flow. The coax shields will be kept very close to one another while exiting the coil assembly to virtually eliminate ground loops.

Detailed Description Text (45):
After reading the above, it should now be readily apparent for people skilled in the art, that several quadrature coils may be overlapped with the birdcage coil and a reliable non-active means may be used to decouple the coils in the array, and to maintain minimum cross-talk between them. The coils mentioned here, may be shaped to provide uniform coverage over the imaging FOV. It may also be noted that the birdcage and the distributed surface coil in the array may be of a low-pass, high-pass, band-pass or band-stop configurations. It should be also apparent by now that the array may be used in any of the operating mode. Also, the traps may be designed slightly different than mentioned above, and that several traps may be employed in the design. The above array may also be un-split (that is, the above array may not be a split-top design).

Detailed Description Text (46):
FIG. 13 represents another embodiment of the invention. Here, coil #1 of FIG. 3 is replaced by a birdcage, and this application is for imaging the head. A two birdcage design was patented by Misic (see U.S. Pat. No. 5,258,717). The present invention adds a third quadrature surface coil of the modified design (see FIGS. 9-11), to the two birdcage coil to further improve the S/N toward the top of the head without compromising B.sub.1 homogeneity. In addition, non-active circuits have been included to decouple the coils and minimize the cross-talk between all coils in the array. This has facilitated newer operating modes, never before offered in the entire MR industry, with particular focus to upper or lower portions of the brain or for routine head studies in one clinical setting, with high S/N and without significantly compromising homogeneity. The following table illustrates the operating modes and individual coil status.

Detailed Description Text (47):
The clinical features of this innovative coil design are its multiple mode operation, viz., (1) upper Brain studies UB; (2) lower brain studies LB; and (3) routine head H.

Detailed Description Text (49):
It is to be noted for all the four designs mentioned above, individual coils in the array may be shaped in such a way to provide a high S/N and uniform coverage over the imaging FOV. The coils may also be used to image in the several operating modes. The signal may be combined prior to the preamplifier or post the preamplifier in analog or digital fashion. The individual coils in the array may be tuned to one or more frequencies. Several traps may be employed in the design. Un-split versions may be used as well.

Detailed Description Text (51):

The advantages of this invention over the prior art are in providing a high S/N over an extended coverage without substantially compromising B.sub.1 homogeneity, in all the operating modes.

Detailed Description Text (52):
The new features of the invention include a unique combination of volume coils, including non-active circuits for decoupling individual coils and to minimize cross-talk between coils in the array; the RF distribution in each coils in the array are independent of one another, with each coil maintaining their own preferred orientation; the invention offers a coil capable of operating in multiple modes without compromising S/N, B.sub.1 uniformity and image resolution; The invention offers multiple studies to be performed in one patient setting; and the invention offers extended FOV coverage without compromising image quality.

Detailed Description Paragraph Table (1):
TABLE 1 Individual Coil Status Operating Modes Coil #1 Coil #2 Coil #3 Head (H) OFF ON ON Neck (N) ON OFF OFF Head and Neck ON ON ON (H & N)

Detailed Description Paragraph Table (2):
TABLE 2 Individual Coil Status Operating Modes Coil #1 Coil #2 Coil #3 Upper Brain OFF ON ON Lower Brain ON OFF OFF Routine Head ON ON ON

Other Reference Publication (2):
"A Comprehensive Analysis for Estimating Modes in Coupled Resonators" by Ravi Srinivasan and Haiying Liu, pp 1425.

Other Reference Publication (3):
"Examples of the Design of Screened and Shielded RF Receiver Coils", by Michael Burl and Ian R. Young, pp 326-330.

CLAIMS:

1. A radio-frequency (RF) coil apparatus for resonance imaging/analysis, comprising:

a first quadrature volume coil;

a second quadrature volume coil at least partially overlapping the first quadrature volume coil; and

a quadrature surface coil at least partially overlapping the second quadrature volume coil and having a magnetic field substantially overlapping a magnetic field of the second quadrature volume coil.

2. The RF coil apparatus of claim 1, wherein the overlapping of the second quadrature volume coil with the first quadrature volume coil and the overlapping of the quadrature surface coil with the second quadrature volume coil is configured to substantially minimize mutual inductance therebetween at a resonance imaging frequency of interest.

3. The RF coil apparatus of claim 1, wherein first quadrature volume coil, the second quadrature volume coil, and the quadrature surface coil are selectively operable to provide a generally uniform magnetic field within a volume formed by the combination thereof at a resonance imaging frequency of interest.

4. The RF coil apparatus of claim 1, wherein the first quadrature volume coil comprises a helmholtz pair coils.

5. The RF coil apparatus of claim 1, wherein the first quadrature volume coil comprises a birdcage coil.

6. The RF coil apparatus of claim 1, wherein the second quadrature volume coil comprises a birdcage coil.

7. The RF coil apparatus of claim 6, wherein the first quadrature volume coil is

located proximate one end of the birdcage coil and the quadrature surface coil is located proximate the other end of the birdcage coil, a length of the birdcage coil being selected such that a head of a patient is received in the birdcage coil during resonance imaging, and the first quadrature volume coil is positioned and sized to encompass a neck of the patient.

8. The RF coil apparatus of claim 7, further comprising coupling circuitry to permit selective imaging of the head, neck and head with neck.

9. The RF coil apparatus of claim 6, wherein the first quadrature volume coil is located proximate one end of the birdcage coil and the quadrature surface coil is located proximate the other end of the birdcage coil, a length of the birdcage coil being selected such that an upper brain portion of a head of a patient is received in the birdcage coil during resonance imaging, and the first quadrature volume coil comprises another birdcage coil which is positioned and sized to encompass a lower brain portion of the patient.

10. The RF coil apparatus of claim 9, further comprising coupling circuitry to permit selective imaging of the upper portion, the lower portion, and the upper portion with the lower portion.

11. The RF coil apparatus of claim 1, wherein the quadrature surface coil comprises a primary coil and a secondary coil coupled together to produce a magnetic B field which is asymmetric relative to an axis of the quadrature surface coil at a resonance imaging frequency of interest.

12. The RF coil apparatus of claim 11, wherein the second quadrature volume coil comprises a birdcage coil .

13. The RF coil apparatus of claim 12, wherein the quadrature surface coil is positioned within and near an end of the birdcage type coil.

14. The RF coil apparatus of claim 13, wherein another end of the birdcage type coil is sized to receive a human head to be evaluated.

15. The RF coil apparatus of claim 1, wherein the first quadrature volume coil includes a first loop coupled to a second loop forming a first mode, a third loop coupled to a fourth loop forming a second mode.

16. The RF coil apparatus of claim 1, wherein the first quadrature volume coil includes two counter-rotating pairs .

17. The RF coil apparatus of claim 16, wherein the counter-rotating pairs are helmholtz pairs .

18. The RF coil apparatus of claim 17, wherein the second quadrature volume coil is a birdcage coil .

19. The RF coil apparatus of claim 1, wherein the RF coil apparatus has multiple mode operation in order to image different areas of a body of an object under investigation.

20. The RF coil apparatus of claim 1, wherein the quadrature surface coil is positioned within and near an end of the second quadrature volume coil.

21. A radio-frequency (RF) coil apparatus for resonance imaging/analysis, comprising:

an RF volume coil sensitive to RF signals produced during resonance imaging/analysis; and

an RF surface coil, also sensitive to the RF signals, physically positioned relative to the RF volume coil to share a common axis and to produce a substantial overlap of the magnetic fields of the respective coils at a frequency of the RF signals.

22. The RF coil apparatus of claim 21, wherein the RF volume coil comprises a birdcage type coil.

23. The RF coil apparatus of claim 22, wherein the RF surface coil is positioned within and near an end of the birdcage type coil.

24. The RF coil apparatus of claim 23, wherein another end of the birdcage type coil is sized to receive a human head to be evaluated.

25. The RF coil apparatus of claim 21, wherein the overlap of the magnetic B fields is asymmetric.

26. The RF coil apparatus of claim 21, further comprising another RF volume coil sensitive to the RF signals and physically positioned relative to the RF volume coil to produce an overlap of the magnetic B fields of the respective coils.

27. A radio-frequency (RF) coil apparatus for resonance imaging/analysis, comprising:

a first quadrature volume coil;

a second quadrature volume coil at least partially overlapping the first quadrature volume coil;

a quadrature surface coil at least partially overlapping the second quadrature volume coil and having a magnetic field substantially overlapping a magnetic field of the second quadrature volume coil; and

coil-to-coil decoupling circuitry for preventing closed ground loops.

28. The RF coil apparatus of claim 27, wherein the coil-to-coil decoupling circuitry comprises coaxial cable traps tuned close to a resonance imaging frequency of interest, a first of said traps being located in a cable providing an RF signal connection to the first quadrature volume coil and a second of said traps being located in a cable providing an RF signal connection to the quadrature surface coil.

29. The RF coil apparatus of claim 28, wherein the first trap is positioned adjacent the overlapping of the first quadrature volume coil and the second quadrature volume coil.

30. The RF coil apparatus of claim 28, wherein the coil-to-coil decoupling circuitry further comprises a guard ring of the second quadrature volume coil.

31. The RF coil apparatus of claim 30, wherein the guard ring functions to provide a ground path for coaxial cables connected to respective RF signal connections of each of the first quadrature volume coil, the second quadrature volume coil, and the quadrature surface coil.

32. A radio-frequency (RF) coil apparatus for resonance imaging/analysis, comprising:

a first quadrature volume coil;

a second quadrature volume coil at least partially overlapping the first quadrature volume coil; and

a quadrature surface coil at least partially overlapping the second quadrature volume coil

wherein the first quadrature volume coil comprises third and fourth volume coils.

33. The RF coil apparatus of claim 32, wherein the third volume coil includes a first counter-rotating pair and the fourth volume coil includes a second counter-rotating pair.

34. The RF coil apparatus of claim 32, wherein at least one of the second quadrature volume coil and the quadrature surface coil comprises a combination of two or more coils.

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L13: Entry 5 of 8 File: USPT Nov 21, 2000

DOCUMENT-IDENTIFIER: US 6150816 A
TITLE: Radio-frequency coil array for resonance analysis

Abstract Text (1):
An RF coil array which includes first and second RF coils that are overlapped to eliminate their coupling (to maintain zero mutual inductance between them) through space, a third coil connecting the first and second coils such that there is no net coupling between the first two coils through the third coil, and in which all three coils are well isolated from one another at the resonance frequency or frequencies of interest.

Brief Summary Text (2):
The present invention relates to resonance systems, such as magnetic resonance imaging (MRI), nuclear quadrupole resonance (NQR), electron spin resonance (ESR) systems, and more particularly to a radio-frequency (RF) coil array and method for use in such systems.

Brief Summary Text (5):
In MRI systems or nuclear magnetic resonance (NMR) systems, a static magnetic field B.sub.o is applied to the body under investigation to define an equilibrium axis of magnetic alignment in the region of the body under examination. An RF field is then applied in the region being examined in a direction orthogonal to the static field direction, to excite magnetic resonance in the region, and resulting RF signals are detected and processed. Generally, the resulting RF signals are detected by RF coil arrangements placed close to the body. See for example, U.S. Pat. No. 4,411,270 to Damadian and U.S. Pat. No. 4,793,356 to Misic et al. Typically, such RF coils are either surface type coils or volume type coils, depending on the particular application. Normally separate RF coils are used for excitation and detection, but the same coil or array of coils may be used for both purposes. For multiple surface RF coils for use in NMR, see U.S. Pat. No. 4,825,162 to Roemer, et al.

Brief Summary Text (6):
A further increase in S/N can be realized with the use of quadrature coils as compared to the conventional linear coil designs. See for example U.S. Pat. No. 4,467,282 to Siebold and U.S. Pat. No. 4,707,664 to Fehn. Also see U.S. Pat. Nos. 4,783,641 and 4,692,705 to Hayes for a quadrature volume coil, commonly referred to as the "birdcage" coil in the NMR community. For the use of multiple volume coils for use in NMR, see U.S. Pat. No. 5,258,717 to Misic, et al., and the reference article by Leussler for the use of multiple volume coils for simultaneous head and neck imaging (See, C. Leussler, "Optimized Birdcage Resonators for Simultaneous MRI of Head and Neck", SMRM 12th Annual Meeting, New York, Book of Abstracts, page 1349, 1993). Also, reference is made to commonly assigned U.S. patent application Ser. No. 08/745,893 filed on Nov. 8, 1996 titled " Radio-Frequency Coil and Method for Resonance Imaging/Analysis", and Ser. No. 08/993,932 entitled "Improved Radio-Frequency Coil and Method for Resonance Imaging/Analysis", filed on Dec. 18, 1997, the disclosures of which are incorporated herein by reference, for the use of multiple volume and surface coils for use in NMR imaging.

Brief Summary Text (7):
The recent introduction of array coils to NMR, has led to commercially available cervical-thoracic-lumbar (CTL) array coil for entire spine imaging, and flexible body arrays for torso imaging. These multichannel coils significantly help reduce

scan times. A routine MR study takes approximately 45 minutes, including the patient placement. This is uncomfortable especially for claustrophobic patients in general. In addition, prolonged scan times make the contrast-enhanced studies even more difficult to obtain. The almost 1 hour MR study with and without the contrast agent makes MR not so suitable for imaging emergency trauma cases.

Brief Summary Text (8):
This necessitates a new array coil with high S/N, that will allow the MR study of the torso, head, spine or joints such as the knee, wrist and shoulder etc., to be performed in reduced scan times. This will significantly reduce patient discomfort and increase patient throughput in a MR scanner. The reduced scan times will also allow MRI systems to be used in scanning emergency trauma patients.

Brief Summary Text (9):
A new area of MRI namely functional MRI or more commonly referred to as fMRI has emerged in the recent years. This technique provides the capability of mapping the brain functions, non-invasively using MR. Unfortunately, a major drawback of this technique is its lack of sensitivity. Once again, a coil with improved S/N will provide a much clear image that will assist in the diagnosis of disorders in the human brain.

Brief Summary Text (11):
NQR is a technique that is capable of locating and uniquely identifying nitrogen for the detection of explosives and/or narcotics, even when contained and concealed by other materials. NQR has potential application in general and medical imaging and industrial measurements, in addition to the detection of either explosives (including land mines) or narcotics. See U.S. Pat. Nos. 5,594,338 and 5,592,083 for the design of an RF coil employed in the NQR system.

Brief Summary Text (13):
Generally, NQR frequencies of quadrapole nuclei lie within 0.5-5 MHz range. However, for organic chlorine compounds, .sup.35 Cl chemical shifts range from 16-55 MHz. The chemical shift of chlorinated hydrocarbons occurs between 32-45 MHz. This is a very wide frequency range for one single turn RF coil of the aforementioned '338 and '083 references to cover.

Brief Summary Text (14):
Even the 0.5 to 5 MHz (a ten fold frequency) range of detection for .sup.14 N in explosives and or narcotics mandate a capacitance of a factor of 100 (f.sup.2 .varies.1/LC) to tune the coil from 5 to 0.5 MHz range, which are overwhelmingly large range of capacitances required to tune the RF coil. Since, the same RF coil was used for a wide frequency range, the RF coil design was un-optimized for the several frequency ranges of operation. This may affect the performance of the RF coil (Q values) and the entire NQR system (transmitter power, S/N), in the detection of low levels of nitrogen compounds found in plastic explosives and narcotics.

Brief Summary Text (15):
This necessitates that the RF coil design be optimized for maximum S/N over at least a majority of the frequency ranges of NQR operation and detection in reduced examination times.

Brief Summary Text (16):
Distributed Type Volume Coils

Brief Summary Text (17):
Birdcage Coil

Brief Summary Text (18):
Even after several years following the introduction of array coils to NMR, the only coil that is commercially used for scanning the human head in a horizontally oriented B.sub.o magnetic field is the quadrature birdcage coil of Hayes '705. Other applications of this coil design are for the whole body, knee and wrist imaging. A birdcage coil consists of two rings connected by several straight segments referred to as legs. A planar schematic of an eight leg high-pass birdcage is shown in FIG. 1a. This coil consists of two end rings R1 and R2 and 8 legs 1 through 8. Each ring

section between two legs are interrupted by two series 2C value capacitors. Their combined effect is one capacitor of C value. FIG. 1b is the front view of the birdcage describing the location of the ring with respect to the legs and includes the mode orientation. FIG. 1c is the side view of the coil outline shown for brevity.

Brief Summary Text (19):
The birdcage which is of the distributed inductance-capacitance type structure has several frequency modes. Of interest is the first or principal or k=1 quadrature mode. This k=1 quadrature mode has two linear components (1a, 1b), oriented orthogonal to one another as shown in FIG. 1b. As mentioned above, the quadrature coil provided a 41% improvement over the conventional linear coil designs. The birdcage expended half the power when compared to the conventional linear coil, thus significantly reduced the RF power deposited in the patient. The higher order or k>1 modes had no net field at the coil center and generally were not used for imaging. At the k=1 mode, the currents in the coil were cosinusoidally distributed such that the resultant field displayed a homogeneous distribution over the imaging field-of-view (FOV). It is for these regions this coil gained popularity in the NMR community for the several volumetric applications (torso, head, knee, wrist, etc.).

Brief Summary Text (20):
The dashed lines of FIGS. 1a, 1b and 1c are planes of symmetry for this birdcage. From FIG. 1b, there are four such planes (I, II, III, IV), that are distributed azimuthally (due to symmetry). There is one additional axial plane (V) that is centrally located between the two end rings R1 and R2, dissecting the coil axis (see FIG. 1c) which, in addition is also a virtual ground plane. The points where the planes of symmetry intersect the birdcage are "a, b, c, d, e, f, g, h" on ring R1 and "i, j, k, I, m, n, o, p" on ring R2, "q, r, s, t, u, v, w, x" on legs 1, 2, 3 . . . 8 respectively of FIG. 1a. Since points "q-x" are located on the virtual ground plane, these points are at virtual ground potential or have no net potential.

Brief Summary Text (21):
Should points "a-p" on the end rings be connected as shown in FIG. 1d, then the 8 leg coil of FIG. 1a will become a 16 leg coil of FIG. 1d and the frequency mode structure including the current distribution will be altered. The resultant structure in this case was still a single birdcage, even after the addition of eight more legs. Thus the increase in S/N was not realized even after this addition, although the homogeneity along the axial planes of the coil may have improved slightly over the eight leg coil. And since no increase in S/N was realized, this approach was unacceptable.

Brief Summary Text (22):
However, should the virtual ground points "q-x" in the legs of FIG. 1a be shorted, this will result in the coil of FIG. 1e. This will give rise to a new RF gradient mode, bi-phasic in nature with + & - lobes along the coil axis. However, it is noted that a RF gradient mode for the coil of FIG. 1e, has no net field at the coil center (i.e., the RF gradient mode has no net field in the central virtual ground plane of FIG. 1c). Therefore, although FIG. 1e has two birdcages that share one end ring R.sub.12 and even a new mode is realized, no net increase in S/N at the coil center is realized.

Brief Summary Text (23):
3-Channel Distributed Type Coil Head Array

Brief Summary Text (24):
A quadrature, 3-channel head coil was described by the inventor in previously filed Ser. No. 08/993,932, which provided improved S/N at the coil center and toward the top of the head (see FIG. 2). The coil consisted of two birdcages (coils #1, #2), one distributed, quadrature modified surface coil (coil #3) and passive circuits were used for decoupling individual coils and to minimize the cross-talk between all coils in the array. The coil was operated in the multiple operating modes, with focus to the upper or lower portions of the brain or for routine head studies in one clinical setting, with high S/N and without compromising homogeneity. Here the birdcage, coil #2 and the quadrature surface coil #3 were asymmetrically overlapped and therefore isolated from one another and is the subject of previously filed U.S.

Ser. No. 08/745,893.

Brief Summary Text (25):
The combination of coils #2 and #3 was then overlapped with birdcage coil #1. Since all three coils in the array were physically separated from one another, and were overlapped to maintain minimal mutual coupling, each coil in the array maintained their own RF current distribution and mode orientation. Several passive coil-to-coil decoupling electronics helped minimize the residual cross-talk between coils in the array. Each quadrature coil signal was routed to individual low noise figure, high gain preamplifiers before digitization. Diode protection circuits were inserted between the coil and the respective preamplifier for preamplifier protection during whole body transmit.

Brief Summary Text (26):
2-Channel Birdcage, Head and Neck Array

Brief Summary Text (27):
A quadrature, 2-channel birdcage array was described in C. Leussler, "Optimized Birdcage Resonators for Simultaneous MRI of Head and Neck", SMRM 12th Annual Meeting, New York, Book of Abstracts, page 1349, 1993 for simultaneous head and neck imaging (see FIG. 3). This coil involved 2 birdcages; a coil 10 for the head and a coil 12 for the neck. The head birdcage 10 had eight fold symmetry, whereas the neck birdcage 12 had only a four-fold symmetry. The neck birdcage 12 had shoulder cut-outs for accomodating the neck as shown in FIG. 3. This coil provided an extended FOV without significantly compromising S/N and homogeneity over the extended FOV. Nevertheless, no increase in S/N was realized over extended FOVs. That is, the S/N of the array coil was comparable to individual head or neck coils over the head & neck scan volume.

Brief Summary Text (28):
Distributed Type Surface Coils

Brief Summary Text (29):
The distributed surface coil of FIG. 4a has three meshes, 4 vertical segments referred to as legs and 2 horizontal segments referred to as ring segments. Each of the ring segments between the legs are broken with two 2C capacitors in series. Like wise, each of the end ring segments are also populated with two 2C value capacitors. For details of this coil design, refer to U.S. Pat. No. 4,783,641 to Hayes, et al.

Brief Summary Text (30):
The coil of FIG. 4a is of the high-pass configuration, and has three resonance modes. The principal or k=1 mode behaves like a simple loop coil of identical outside coil dimension of FIG. 4a (see FIG. 4b). The k=2 mode will behave similar to a butterfly design of FIG. 4c. Dashed lines I, II and III merely depict the mid voltage points "a-f" between 2 capacitors of identical values, whereas line IV is a virtual ground plane and points "g-j" are at virtual ground potential or have no net potential.

Brief Summary Text (31):
The main advantages of the distributed type coil designs are its distributed sinusoidal currents that help provide uniform B field distribution, and reduced losses. Also, the field profiles lay close to the coil which minimize tissue losses from the human body, thus increases coil S/N.

Brief Summary Text (32):
A multiple surface coil arrangement disclosed in U.S. Pat. No. 5,256,971 to Boskamp is shown in FIG. 4d. Here, two surface coils of similar dimension are overlapped for minimum mutual inductance from one another. A third coil is added to this set, such that the third coil is magnetically isolated from the first and second coils. Here, all three coils are mutually isolated from another. In doing so, the third coil has a different coil geometry than the first and second coils, and extends beyond the FOV of the first and second coils combined.

Brief Summary Text (33):
Should this arrangement of coils be flexed around the human torso, the isolation

between the third coil and the first and second coils will change, which in turn will affect the isolation between the first and second coils, as the first and second coils will now start to couple via the third coil. That is, should the third coil begin to couple to either the first or second coils, all coils in the array will begin to couple with each other. This was not satisfactory.

Brief Summary Text (34):
This necessitates a coil system where the individual coils in the system are well isolated from one another and still maintain its current distribution and preferred mode orientation irrespective of its shape.

Brief Summary Text (35):
Single and Multiple Turn Solenoid Type Coils

Brief Summary Text (36):
Solenoid Coil for NMR

Brief Summary Text (37):
One of the oldest and perhaps the most popular coil design that is commercially utilized for the several volumetric applications (torso, head, spine, knee, wrist) is of the solenoid design. See for example, U.S. Pat. No. 4,398,148 to Barjhoux et al.

Brief Summary Text (38):
FIG. 5a is one example of a solenoid head coil configuration commonly used in the NMR community. The N-turn solenoid is resonated with two series connected 2C value capacitors. This coil has 2 planes of symmetry, I and II, respectively. Plane I intersects the coil at virtual ground points "a , b". A side view of the coil outline along with the head and the central virtual ground plane I is shown in FIG. 5b, for brevity.

Brief Summary Text (39):
Shorting the two virtual ground points of FIG. 5a will result in FIG. 5c. This will give rise to a new RF gradient mode along the coil axis. It will be noted that a RF gradient mode has no net field at the coil center (i.e. the RF gradient mode has no net field in the central virtual ground plane of FIG. 5b). Therefore, although FIG. 4c has two solenoid coils sharing the two virtual ground point "a, b" of FIG. 5a and even a new gradient mode is realized, the homogeneous mode of FIG. 5a will not be affected and no net increase in S/N is realized at the coil center.

Brief Summary Text (41):
A single turn solenoid coil of FIG. 6 was used to detect the .sup.14 N signals in crystalline form for detecting concealed explosives and narcotics employing nuclear quadrupole resonance (NQR). See U.S. Pat. Nos. 5,594,338 and 5,592,083 for the design of an RF coil employed in the NQR system.

Brief Summary Text (42):
FIG. 6 has one single turn RF coil which is tuned to a wide range (approx 0.5 to 5 MHz), by simply adding large and small value capacitances for coarse and fine tuning with the help of relay switches. As seen, the upper frequency range was ten fold of the lower range which mandated a 100 fold change in capacitance to tuned the coil. Since, the same RF coil was used for a wide frequency range, the RF coil design was un-optimized for the several frequency ranges of operation. This may affect the performance (transmitter power, S/N) of the RF coil and the entire NQR system, in the detection of low levels of nitrogen and chlorine compounds found in plastic explosives and narcotics.

Brief Summary Text (43):
This necessitates that the RF coil design be optimized for at least a majority of the frequency ranges of NQR operation and detection which will also help in reducing examination times.

Brief Summary Text (44):
This RF coil design will allow for at least one optimized coil in the array that will cover a part of the frequency spectrum, such that all coils in the array

combined cover the entire frequency spectrum required for detection. This will help reduce the overall scan frequency range per coil and thus allow rapid tuning of coils in the array. This RF coil design may also be designed to allow for multiple tuning of the coils in the array without crosstalk and capable of simultaneous operation, which will help scan the entire frequency range in reduced scan times.

Brief Summary Text (45):
It is therefore a primary objective of the present invention to further improve S/N and reduce scan times of all such coil systems used for resonance imaging or spectroscopic analysis mentioned above. Specific applications of the coil described herein in accordance with the present invention include distributed type surface and volume coils, and single and multiple turn solenoid type coils.

Brief Summary Text (47):
The present invention provides an RF coil with high signal-to-noise ratio (S/N) over the imaging or spectroscopic field-of-view (FOV). The RF coil of the present invention enables one to reduce scan times and therefore patient discomfort without significantly compromising image quality. The RF is capable of operating in different FOVs in the multiple operating modes in one or multiple frequencies. Furthermore, the present invention provides a coil array capable of simultaneous operation in at least one frequency range.

Brief Summary Text (48):
A primary objective of the present invention is to provide a novel RF coil design with high S/N, capable of array operation in the single or multiple frequencies. Another objective is to provide an array design, which will provide a high combined S/N than any one coil operated alone. Yet another objective is to provide a RF coil capable of simultaneous multiple frequency operation for resonance imaging/spectroscopic analysis. A further objective is to have coils in the array that are well isolated from one another and maintain their individual current distributions and mode orientations irrespective of the shape of the coil.

Brief Summary Text (49):
The design of the inventive coil involves first and second RF coils, that are overlapped to eliminate their magnetic coupling (to maintain zero mutual inductance between them) through space, a third coil physically connecting the first and second coils such that there is no net coupling between the first two coils through the third coil, and all three coils are well isolated from one another at the resonance frequency or frequencies of interest.

Brief Summary Text (50):
Please note all three coils in this coil system (first+second+third), may be volume type coils or surface type coils or a combination of both. A novel aspect of this invention is the unusual combination of coils in one integrated structure, that are well isolated from another and maintain their preferred current distributions and mode orientations.

Brief Summary Text (51):
In the embodiments of the present invention, the third coil has a FOV nearly identical to that of the combined FOV of the first two coils, and overlaps the combined FOV of the first two coils, such that, the S/N of all three coils combined is greater than any one coil operated alone. In other embodiments, several (first+second+third=integrated) such integrated coils are overlapped for minimal mutual inductance and used in an array configuration. The three individual coils in any one integrated design may be tuned to one or more resonance frequencies, for simultaneous use in imaging or spectroscopic analysis. Depending on the imaging FOV, individual coils in the array can be turned OFF or ON by the programmable transmit/receive (T/R) driver in the resonance system.

Brief Summary Text (52):
According to one particular aspect of the invention, a radio-frequency (RF) coil array for resonance imaging/analysis is provided. The coil array includes a first RF coil sensitive to RF signals produced during resonance imaging/analysis; a second RF coil located relative to the first RF coil with substantially zero coupling therebetween at a frequency or frequencies of the RF signals; and a third RF coil

located relative to the first RF coil and the second RF coil such that there is substantially zero net current flow between the first RF coil and the second RF coil via the third RF coil, each of the first RF coil, second RF coil and third RF coil being substantially isolated from the other coils at the frequency or frequencies of the RF signals.

Drawing Description Text (2):
FIG. 1a is a planar schematic view of a high-pass birdcage coil ;

Drawing Description Text (3):
FIG. 1b is a is a schematic end view of the birdcage coil of FIG. 1a;

Drawing Description Text (4):
FIG. 1c is a side schematic view of the birdcage coil of FIG. 1a illustrating the plane of symmetry;

Drawing Description Text (5):
FIG. 1d is a planar schematic of a modified birdcage coil of FIG. 1a;

Drawing Description Text (6):
FIG. 1e is a planar schematic of a modified birdcage coil of FIG. 1a;

Drawing Description Text (7):
FIG. 2 is a schematic view of an RF coil having two birdcage coils, and modified spoke type quadrature surface coil ;

Drawing Description Text (8):
FIG. 3 is a perspective view of a quadrature, 2-channel birdcage array ;

Drawing Description Text (9):
FIG. 4a is a schematic view of a distributed type surface coil ;

Drawing Description Text (10):
FIGS. 4b and 4c represent the principal and secondary modes, respectively, for the coil of FIG. 4a;

Drawing Description Text (11):
FIG. 4d represents a three coil arrangement of Boskamp et al.;

Drawing Description Text (12):
FIG. 5a represents schematically a solenoid head coil;

Drawing Description Text (13):
FIG. 5b is a side view of the coil outline of FIG. 5a;

Drawing Description Text (14):
FIG. 5c is a modified version of the coil of FIG. 5a;

Drawing Description Text (15):
FIG. 6 is a schematic illustration of a single turn solenoid coil ;

Drawing Description Text (16):
FIG. 7a is a simplified illustration of a coil array in accordance with the present invention in which three coils are shown with respective current distributions;

Drawing Description Text (17):
FIG. 7b is a schematic illustration of the coil in accordance with the present invention;

Drawing Description Text (18):
FIG. 7c is a flowchart representing exemplary steps for manufacturing a coil array in accordance with the present invention;

Drawing Description Text (19):
FIG. 7d is a schematic view of exemplary isolation circuits in accordance with the

present invention;

Drawing Description Text (20):
FIG. 7e is a schematic view of an exemplary coupling mechanism in accordance with the present invention;

Drawing Description Text (21):
FIG. 7f is a table illustrating various combinations of individual coils for different modes of operation in accordance with the present invention;

Drawing Description Text (22):
FIG. 7g is a schematic illustration of a plurality of coils in combination in accordance with the present invention;

Drawing Description Text (23):
FIG. 8a is a planar schematic view of another embodiment of the coil array in accordance with the present invention;

Drawing Description Text (24):
FIG. 8b is a schematic front view of the coil array of FIG. 8a;

Drawing Description Text (25):
FIG. 8c is a side view of the coil outlines of the array of FIG. 8a;

Drawing Description Text (26):
FIG. 8d is a schematic view of a 4-channel, quadrature head array in accordance with the present invention;

Drawing Description Text (27):
FIGS. 9a and 9b are front and side views of a 3-channel, quadrature knee array embodiment in accordance with the present invention;

Drawing Description Text (29):
FIGS. 10a and 10b are, respectively, schematic front and side views of a 3-channel, quadrature wrist array in accordance with the present invention;

Drawing Description Text (30):
FIG. 11a is a planar schematic view of a 3-channel, quadrature head and neck array in accordance with the present invention;

Drawing Description Text (31):
FIG. 11b is a front view of the coil array of FIG. 11a;

Drawing Description Text (32):
FIG. 11c is a modified coil of FIG. 11a including the addition of a fourth coil;

Drawing Description Text (33):
FIG. 12a is a schematic view of a distributed coil array for spine or torso imaging in accordance with the present invention;

Drawing Description Text (34):
FIG. 12b is a schematic view of a modification of the coil array of FIG. 12a in which a fourth coil is formed;

Drawing Description Text (36):
FIG. 13a is a schematic illustration of a solenoid type volume coil in accordance with the present invention;

Drawing Description Text (37):
FIG. 13b is a schematic view of a preferred embodiment of the coil in FIG. 13a in accordance with the present invention; and

Drawing Description Text (38):
FIG. 14 is a block diagram of a system incorporating an coil in accordance with the present invention.

Detailed Description Text (3):
Referring initially to FIG. 7a, the invention includes first (coil #1) and second (coil #2) RF coils, that are overlapped to isolate the coils from each other, by causing the net shared flux between the coils to be zero. A third RF coil (coil #3) of FIG. 7a, is superimposed on the combination of coils #1 and #2, and physically connects coils #1 and #2 at several points along the coil periphery (see FIG. 7b). For the sake of explanation, the coil #3 may connect to coils #1 & #2 at points A, B and A', B' respectively. This however is done such that there is no net coupling between coils #1 and #2 through coil #3. Thus coils #1 and #2 are isolated from one another and still maintain their individual current distributions and B field orientations. Also, the currents in coil #3 are undisturbed and maintain their original distribution and B field orientation. Thus, all three coils are well isolated from one another and perform the intended function in a resonance experiment independent of the other.

Detailed Description Text (4):
Only coil outlines are shown in FIG. 7a for brevity. Not shown are impedances (inductances & capacitances) needed to resonate the RF coil at the frequencies of interest. It will be appreciated that the individual coils of FIGS. 7a may be of the volume type or the surface type or their combination as is discussed more fully below in connection with the specific embodiments.

Detailed Description Text (5):
Individual current distributions of coils #1, #2 and #3 are shown in FIG. 7a. Accordingly, their resultant B field orientations are directed in to the plane of the paper (if the fingers of the right hand are curled in the direction of the current, according to the right hand rule, the resultant B field direction of the coil is in the direction of the thumb, and in this case will be pointing in to the plane of the paper). By way of overlapping coils #1 and #2 are isolated from one another and maintain their individual current directions and preferred mode orientations. Here mode is referred to as the frequency mode of interest for a resonance experiment. For the cases of NMR or NQR, the modes of interest may be for one or more distinct radio-frequencies . However, mode orientations are the orientations of the B field over the imaging or the spectroscopic field-of-view (FOV) for individual RF coils, at the frequencies of interest. That is, for a linear RF coil case, there exists one mode that is of interest and one mode orientation. However, for a quadrature RF coil case, there exists two linear modes that are oriented orthogonal to one another. These two linear modes however may be tuned to the same frequency resulting in a quadrature coil, or may be tuned to two distinct frequencies thus depicting a dual tuned RF coil with linear operation at both frequencies.

Detailed Description Text (6):
Although it is preferred that coils #1 and #2 maintain identical coil dimensions, it is not an absolute necessity. In fact included in this disclosure is a head and neck array, where coils #1 and #2 are not identical in dimension. Nevertheless for the sake of simplicity, coils #1 and #2 of FIG. 7b have identical dimensions. Coil #3 connected to this combination of coils #1 and #2, encompasses a larger FOV covered by coil #1 or #2 alone. In fact, the FOV of coil #3 in this case is not only comparable but also superimposes the combined FOV of coils #1 and #2.

Detailed Description Text (7):
The combined S/N of coils #1 and #2, at the coil center (at the region of overlap) may be close or equal to the S/N of coil #3 of FIG. 7a. Thus the combined S/N of all three coils, that are isolated from another will be substantially greater than any one coil in the array. This is because the direction of currents in all three coils will remain the same and have similar B field orientations. Hence signals from all three coils add up. Since they are isolated from one another the noises from the coils in the array are uncorrelated, resulting in a substantial increase in combined S/N. For details of the mathematical expressions of combined S/N, refer to equations 19 and 20 of U.S. Pat. No. 4,825,162 of Roemer et al.

Detailed Description Text (8):
Coil Optimization Procedure

Detailed Description Text (9):
Since the inventive design has three coils in one integrated system, all coils must be isolated from one another to reduce their cross-talk which is necessary to increase the combined S/N of an experiment. In order to cancel the magnetic coupling between neighboring coils, they must be overlapped to cancel their net shared flux. The flow chart of FIG. 7c, represents a procedure suitable for optimizing all coils in the integrated coil system of FIG. 7b.

Detailed Description Text (10):
In steps S1 and S2, the first coil #1 is built and tested individually. Next, in step S3 the second coil #2 is built. In step S4, coil #1 and #2 are overlapped to cancel their coupling. Namely, in step S5 it is determined whether coils #1 and #2 are isolated by a predefined acceptable amount (e.g., coupled by less than -20 dB). If no in step S5, the coils #1 and #2 are repositioned relative to each other in an effort to improve the isolation therebetween. Steps S4 and S5 can then be carried out until acceptable isolation is achieved. If yes in step S5, the combined coils #1 and #2 may be tested as represented in step S6.

Detailed Description Text (11):
Then coil #3 will be built and added to this assembly as represented in step S7. After this addition, should the isolation between coils #1 & #2 deteriorate as determined in step S8, then either coils #1 & #2 be overlapped to compensate for the cross-talk introduced by the addition of coil #3 or the mechanism of FIG. 7d be used or a combination of both can be used to reisolate coils #1 & #2 after the addition of coil #3. (Step S9). Overlapping coils #1 & #2 again will cancel the net mutual flux shared by coils #1 & #2 after the introduction of coil #3. Final testing of the assembled array can then be carried out in step S10 upon achieving acceptable isolation between the respective coils. Once this optimum overlap is determined, a relatively high precision of duplication can be achieved from one coil batch to another in mass production, by etching the two coils on one or both sides of a single printed circuit board. However in addition to the above, any cross-talk by way of current flow between coils #1 & #2 via coil #3 can be minimized or eliminated in some instances by following the mechanism of FIG. 7d. Furthermore, if there exists any residual cross-talk, this too can be minimized or eliminated by introducing electrical coupling cancellation networks, one example may be similar to that of U.S. Pat. No. 4,769,605 to Fox.

Detailed Description Text (12):
It will be appreciated that FIG. 7c represents exemplary steps, many of which are optional. For example, the testing of the coils in steps S2 and S6 may be omitted in view of only final testing in step S10.

Detailed Description Text (13):
From FIG. 7b, coil #3 connects to coils #1 & #2 at points A, B & A', B', respectively. If points A, B & A', B' were mid-points between two identical capacitors, then their voltage will be an average of the two potentials spanned by the two identical capacitors. This average potential may be denoted as being equal to V. In the present case, when coils #1 & #2 are identical, points A & A' in coils #1 & #2 will be at equi-potential. Similarly, points B & B' will also be at equi-potential. Please note, points B & B' may or may not be at the same potential as points A & A', which will depend on either the coil symmetry, or the distrubution of impedances within the coil or a combination of both. Since there will be no current flow between points of equi-potential, there is not net coupling between coils #1 & #2 via coil #3 with its addition. That is, the isolation between coils #1 & #2 will remain virtually the same with or without the addition of coil #3. Note, this will be true only if the net flux shared by coils #1 & #2 are close to zero or the cross-talk between them is almost negligible or both the above conditions are satisfied, before the adddition of coil #3.

Detailed Description Text (14):
For example (see FIG. 7d), let V1 and V2 be the voltages spanned by the two identical capacitors C1, then point A midway between V1 & V2 will be at a potential V.sub.A =V=(V1+V2)/2. In reality, this is an ideal case where the two capacitors are identical in value. However, since 5% tolerance capacitors are generally used in

manufacturing, point A may not always be at potential V. Here, point A can be forced to be at potential V by adding or taking away some capacitance value thereby balancing the potential across the capacitors and forcing the points mid-way between them to be at their average values. In the cases where all coils are etched on to a printed circuit board, then the capacitances on the coil can be slightly altered with the addition or subtraction of either small value fixed or trimmer capacitors across C1 and C2 to isolate the coils in the array.

Detailed Description Text (16):
It is by these ways (cancelling net mutual shared flux or isolating with any other scheme, proposed additional isolation scheme of FIG. 7d and/or that of Fox, with the above) the isolation between the above coils can be maintained if all coils were fixed or etched on a rigid or on a flexible printed circuit board. Note, an isolation of -20 dB was set as a target. In actuality, this value can be set to any other number based on the coil design and expected combined S/N. We set a -20 dB value, as this will relate to a 1% loss in combined S/N from the optimum value obtained at coil overlap for coils of identical dimension. For details of coil isolation values and its relation to S/N, please refer to the article by Tropp et al., in the Review of Scientific Instrumentation, Volume 62, Number 11, November 1991.

Detailed Description Text (17):
Finally, although it is advantageous to test the individual coils separately as they are built (like that shown in FIG. 7c), once the optimum settings of the coils and isolation values are engineered and specifications met, then simply final testing of the entire RF coil system (consisting of coils #1, #2 and #3) is advised. This will considerably cut the time and costs incurred in the final production line prior to product shipment. However, the proposed flow-chart is a methodical progression of the coil design which is also designed so to enable a relatively easier debugging or trouble shooting of the coil system when needed.

Detailed Description Text (18):
Individual Coil Coupling

Detailed Description Text (19):
A preferred method of coupling to individual coils in the RF coil array and interfacing to the system is shown in FIG. 7e. Let us assume the case when all coils in the array of FIG. 7b are in quadrature. Then there will be a total of six linear modes, operating at the resonance frequency of interest. These modes are a1 & a2 of coil #1, b1 & b2 of coil #2 and c1 & c2 of coil #3, respectively.

Detailed Description Text (20):
Generally, the linear modes of a coil are matched to 50 ohms using balanced matched capacitors (not shown) and connected to quadrature hybrids via baluns. Either 50 ohm "criss-cross" discrete network (X.sub.L =X.sub.C =50 ohms; L=124nH, C=50 pF for approx. 64 MHz or 1 .5 T) or shielded, transmission line networks such as coaxial cable traps tuned to frequencies very close to the resonance frequency may be used as baluns to convert the balanced feed to an unbalanced line (see FIG. 7e). This is done to isolate the coil grounds from the system ground and to prevent leakage of the circulating RF currents on the ground shield of the coaxial cable exitting the system.

Detailed Description Text (21):
These networks (discrete or transmission line) are shielded as shown by the dotted lines to minimize their interaction with the whole body transmit field and their interaction with the RF coils themselves. Note, it is not necessary to shield the discrete networks but are shown as the preferred embodiment. However, we prefer that the cable traps be shielded so the fields generated by the traps are contained to within the volume encompassed by their shield. This is also done so the cable trap can be made uni or bi directional, depending the nature of the trap's use. The cable trap shown can be made uni directional by shorting its shield to one side of the coaxial cable shield. Likewise it can be made bi-directional by floating the shield, as shown in FIG. 7e.

Detailed Description Text (22):

The cable trap consists of two turns 1" in diameter, is wound on a delrin spindle with groves, using a semi-rigid cable of 0.085" o.d. along with fixed and variable capacitors for tuning a specified frequency range centered around the resonance frequency of operation. The RF shield is approximately 1.5.times.1.5.times.0.5" in dimension.With inductor Q values (of that of L in the discrete or that created by the coaxial cable in the transmission line network) of approximately 175-200, impedances (with zero reactances=resistance) of approximately 8-12K.OMEGA. can be realized across the baluns, which is adequate to isolate the grounds at 64 MHz (Resistance R=Q.omega.L). Thus coil to ground leakage and coil to coil interactions be minimized or eliminated and high RF coil efficiences can be maintained.

Detailed Description Text (23):
Then the linear signals are combined using a phase shifting network to create a single quadrature output per coil. This is followed by a diode protection network before the preamplifier. All three coils are actively decoupled during whole body transmit (circuitry not shown). Although this decoupling will achieve a-25 dB isolation per coil at the resonance frequency of operation, the additional series-shunt pin-diode protection circuit shown will provide a further -45 dB of isolation between the coil and the preamplifier in every channel. During whole body transmit, diode D1 is turned ON which shunts all the RF present in the signal line to ground before reaching the preamp. Diode D2 is reverse biased during transmit and helps further isolate the RF present in the signal conductor to the preamp input. During receive D1 is reverse biased and D1 is forward biased to allow all of the RF signals to the preamplifier before digitization and further amplification at the system receiver. Thus the diode circuit will ensure a safe preamp operation (preamp input maximum of roughly +20 dBm).

Detailed Description Text (24):
Thus all 3 coils are interfaced to 3 channels in a resonance receiving system. It is to be noted, that this way of interfacing the coils to the system is preferred. However, the outputs from the individual coils can be further combined and interfaced to fewer channels of the resonance system. For example, the quadrature outputs from coils #1 & #2 or from all coils #1, #2 & #3 can be combined prior to interfacing to the system, the latter case resulting eventually in a single channel. Likewise, individual modes from all coils can be interfaced to their respective channels (in this case six channels, two from each coil) of the transceiver of a resonance system.

Detailed Description Text (25):
Mode of Operation

Detailed Description Text (26):
Regardless of the frequency of operation, please note the individual coils of FIG. 7b can be turned ON or OFF using the programmable T/R drivers of the resonance system which will result in a total of 7 modes of operation for this 3 coil network, as shown in FIG. 7f.

Detailed Description Text (27):
For example in one configuration, coils #1 and #2 are turned ON and coil #3 is turned OFF. Likewise, coil #1 is turned ON and coils #2 and #3 are turned OFF. All such combination of coils are shown in FIG. 7f. Only two such combinations currently seem not possible, where coil #3 is ON and coil #1 is ON (coil #2 turned OFF) or where coil #3 is ON and coil #2 is ON (coil#1 turned OFF). This is because if one of two coils #1 or #2 are turned OFF, then coil #3 will couple to coils #2 and #1, respectively through space since the minimum mutual inductance condition was not achieved between them. However, it should be understood that one skilled in the art can counteract this unwanted coupling with the addition of electrical cancelling networks or some modification of the coils themselves or a combination of both.

Detailed Description Text (28):
RF Coil System Arrays

Detailed Description Text (29):
Finally, several of these integrated (coil #1+coil #2+coil #3) coil systems, may be overlapped to provide high combined S/N over extended FOVs, as shown in FIG. 7g.

Detailed Description Text (30):
In summary, coils #1, #2 and #3 may be linear or quadrature and of the volume type or surface type or their combination. Should the coils be of the volume type, the dashed line of FIG. 7b will be along the common coil axis. Also, the coils may be tuned to the same or different resonance frequencies. For example, coils #1, #2 and #3 may be tuned to the same resonance frequency. In an another example, coils #1 and #2 may be tuned to one resonance frequency, and coil #3 is tuned to another resonance frequency. In yet another example, the individual coils in the array are tuned to different resonance frequencies and capable of simultaneous operation.

Detailed Description Text (31):
A few examples of the above concept are extended to distributed type volume coils like the birdcage, distributed surface coils and solenoid type coils. Their specific applications to NMR and NQR are described as embodiments of the present invention disclosure.

Detailed Description Text (32):
Embodiment #2--3 Channel, Quadrature Birdcage Array

Detailed Description Text (33):
Embodiment #2 of this invention is the receive only coil of FIG. 8a. This consists of two birdcages (#1, #2) overlapped to maintain minimum mutual inductance, such that the net flux shared by them is zero. Coil #1 consists of rings R1, R2 and eight legs (1,2,3 . . . 8) that connect them. This coil is resonated with C1 value capacitors. Coil #2 consists of R3 and R4 and eight legs that connect them and are also resonated with C1 value capacitors. Note, the 8 legs of coil #2 are co-linear to that of coil #1. Here, both coils #1 and #2 are identical in dimension. Coil #3 connects coil #1 and #2 at 16 points. Coil #3 comprises of rings R1 and R4 which are connected by eight legs (9, 10, . . . 16). Coil #3 is resonant with C1 and C2 value capacitors. All coils are tuned to the same resonance frequency of interest.

Detailed Description Text (34):
After the addition of C2 to coil #3, the isolation between coils #1 and #2 remained virtually the same, which means that the eight legs of coil #3 intercepted rings R1 and R4 at corresponding equi-potential points. In this particular case, the eight legs of coils #1 and #2 happened to be at the symmetry planes for coil #3. Thus there was no net coupling between coil #1 and #2 via coil #3. There was also no net coupling between coil #3 and coils #1 or #2. Thus each coils maintained their own current distribution and their own mode distributions.

Detailed Description Text (35):
FIG. 8b is a front view of the coil, and shows the location of the legs of the birdcage and their mode orientations of the six linear modes of coils #1, #2 & #3 (a1, a2, a3, b1, b2, b3). Closed dark dots are locations of the legs of coils #1 & #2 connecting end rings R1 & R3 to R2 & R4 respectively, whereas open circles are for coil #3 which connect to end rings R1 and R4 only.

Detailed Description Text (36):
FIG. 8c is a side view of the coil outlines, with a head cartoon. As seen, coil #1 coverage extends from the c2-c3 cervical-spine and extends to the top of the cerebellum, coil #2 coverage extends from the mid cerebellum to the top of the head, whereas coil #3 coverage spans the combined FOV's of coils #1 & #2, respectively. Thus, routine head scanning can be accomplished with enhanced S/N, which can be used to reduce scan time or enhance image resolution or a little bit of both can be accomplished with the inventive coil. Furthermore, where specific focus is needed, either coil #1 or coil #2 can be individually turned ON to scan different portions of the human brain. Coupling to the six linear modes of this coil and their interface to the system can be accomplished similar to FIG. 7e. Here, three quadrature coil outputs are interfaced to 3 channels of a NMR system.

Detailed Description Text (37):
Embodiment #3--4 Channel, Quadrature Head Array

Detailed Description Text (38):

A quadrature, 3 channel head coil was described by the author of this invention in the previously mentioned application Ser. No. 08/993,932. See FIG. 2 for details. The S/N of this prior art coil can be further improved over the entire brain with the addition of coil #3, of FIG. 8d. This is also similar to adding coil #4 in FIG. 8c, needed to provide improved S/N over regions in the top of the head.

Detailed Description Text (39):
Coils #1, #2 and #3 have eight legs. Coil #4 is of the self-shielded type and has a total of 16 legs (8 primary and 8 secondary). See the above-mentions application Ser. Nos. 08/745,893 and 08/993,932 for the details of the coil #4's design and construction. Each of the four quadrature outputs from the coils in the head array are interfaced to 4 channels of the resonance receiving system, in this case a NMR receiving system. Please note, all four coils have a shielded, tuned coaxial cable trap in addition to the coupling and interface electronics mentioned in FIG. 7e. These coaxial cable traps help further isolate the RF coil grounds at the preamplifier level to the system ground and interfaces the coil outputs to the system receiver.

Detailed Description Text (40):
Please note, individual coils in the array can be turned ON or OFF to image a smaller FOV than the entire coil. If the focus was on the upper parts of the brain, only coils #2 and #4 need be turned ON, whereas if the focus was on the mandible areas only coil #1 may be turned ON.

Detailed Description Text (41):
Embodiment #4--3 Channel, Quadrature Knee Array

Detailed Description Text (42):
FIG. 9a and 9b are front and side views showing the coil outlines of the knee array. Here, coils #1, #2 and #3 have 4 legs, each. Legs 1, 2, 3 and 4 belong to coils #1 and #2 while 5, 6, 7 and 8 belong to coil #3. All legs are azimuthally distributed as shown in FIG. 9a. Coils #1 and #2 are first overlapped to maintain minimum mutual inductance. Coil #3 is then added which physically connects to coils #1 and #2, such that there is no net coupling between coil #1 and #2 via coil #3. A side view of the coil outlines along with a knee cartoon is shown in FIG. 9b.

Detailed Description Text (43):
FIG. 9c is a modified knee array. Here, coils #1 and #2 have 8 legs (1,2,3 . . . 8) each, distributed in the fashion shown. These coils are first overlapped to maintain minimum mutual inductance. Coil #3 that physically connects coils #1 and #2 have only 4 legs (9,10,11,12) which are distributed symmetrically. This arrangement is done to image the foot and the ankle along in addition to imaging the knee and the human calf. Please note, the coils of FIGS. 9 may have a split-top to ease the patient access.

Detailed Description Text (44):
Embodiment #5--3 Channel, Quadrature Wrist Array

Detailed Description Text (45):
FIGS. 10a and 11b are front and side views of a 3 channel, quadrature wrist array. Coils #1 and #2 have 4 legs (1,2,3,4) and are overlapped for minimal mutual inductance. Coil #3 that connects coils #1 and #2 has four legs (5,6,7,8). Thus the entire wrist array has a total of 8 legs as shown in FIG. 10a. Please note, the opening of the wrist coil is elliptical in shape to accommodate imaging of the fingers of the human hand. This also facilitates lateral placement of the coil along side the patients body inside a MRI machine. This high S/N coil allows for high-resolution imaging of the carpal ligaments of the human wrist.

Detailed Description Text (46):
Embodiment #6--3 Channel, Quadrature Head and Neck Design

Detailed Description Text (47):
A planar schematic of the coil is shown in FIG. 11a. Coil #1 has 8 legs (1,2,3 . . . 8) and covers the head FOV. Coil #2 has 8 legs (1,2,3 . . . 8) and has shoulder cut outs to accomodate the entire human neck. Each of these coils are resonant at the

NMR frequency. Coil #1 and #2 are overlapped for minimal mutual inductance. Coil #3 connects coil #1 and #2 at eight points and hence has 4 legs distributed at right angles from one another. Thus the entire head and neck coil has 12 legs. Here, coil #1 is resonant with C1, and coil #2 is resonant with C2 whereas coil #3 is resonant with C1, C2 and C3, respectively. A front view of the coil is shown in FIG. 11b.

Detailed Description Text (48):
Here, just coil #1 or coil #2 can be turned ON for performing head or neck only studies. Also, all coils (#1, #2 & #3) can be turned ON to perform extended FOV head and neck studies, simultaneously. In this case where coil #3 spans a similar FOV as the combined FOVs of coils #1 & #2, the signals add up and since the noises are uncorrelated, enhanced S/N will be realized, unlike the prior art of FIG. 3. Also, coil #4 of FIG. 8d, can be added to the 3 channel, quadrature coil of FIG. 11 to further improve the S/N toward the top of the head (see FIG. 11c).

Detailed Description Text (49):
Embodiment #7--Distributed Surface Coil Array for Spine and Torso

Detailed Description Text (50):
FIG. 12a is a distributed surface coil array for brain of torso imaging. Here, coil #1 and #2 are overlapped to maintain minimum mutual inductance. Therefore, the net flux shared by these two coils is zero. Both these coils are identical in dimension. They comprise of 2 ring segments, 4 legs and are resonated with C1 value capacitors. These coils are matched to 50 ohms, across the terminals "a, b" similar to the circuit of FIG. 7e and interfaced to 2 channels of the MRI system. Evidently, these two outputs can be matched and summed using a phase shifter, resulting in a single channel quadrature output.

Detailed Description Text (51):
Coil #3 consists of 2 ring segments and 3 legs that connect to coils #1 and #2. Coil #3 is tuned to the resonance frequency of interest with C1 and C2 value capacitors. Coil #3 is matched to 50 ohms across "c" terminal using the similar circuitry of FIG. 7e. After the addition of coil #3, the isolation between coils #1 and #2 remained virtually the same, is indicative of a well isolated system. Please note, one integrated RF coil unit I comprises of coils #1, #2 and #3, respectively.

Detailed Description Text (52):
FIG. 12b is an extension of FIG. 12a, where coil #3 has an additional ring segment resulting in coil #4 on the same coil system. This coil is tuned to the resonance frequency of interest with C1, C3 and C4. Coils #1 and #2 here are tuned with C1, whereas coil #3 is tuned with C1 and C3. The outputs "a, b" can either be routed to two receiver channels, or combined using a phase shifting network resulting in a single quadrature output. Similarly, the other two outputs, "c, d" can be either routed to two other receiver channels or combined prior to the receiver. Please note, one integrated RF coil unit I comprises of coils #1, #2, #3 and #4, respectively.

Detailed Description Text (53):
FIG. 12c is a result of many such integrated RF coil circuits I, II, . . . of FIGS. 12a or 12b, in an array configuration. The coils of FIGS. 12 may be used to image the spine or wrapped around the human torso for imaging the liver, kidney, heart, etc. They may also be used to scan both feet for imaging the blood flow.

Detailed Description Text (54):
Embodiment #8--Solenoid Type Volume Coil

Detailed Description Text (55):
The solenoid type volume coil of FIG. 13a has multiple uses. It can be used to image the human brain, knee, elbow, wrist, foot and ankle, torso in a vertical field NMR machine. This type of a coil may also be used in a NQR system and used to detect the explosives and narcotics in baggages, mails, etc. The NQR system may also be used as a security check at various public places, such as airports, railway stations,etc. and may be used to detect for plastic explosives, narcotics, etc.

Detailed Description Text (56):

FIG. 13a consists of a total of 3 solenoid coils. Coils #1 and #2 are identical in dimension. They both have 2 turns separated by a set distance and are tuned with C1 value capacitors. These coils are overlapped to maintain minimum mutual inductance, thus the net flux shared by these two coils are zero. Coil #3 is then introduced by shorting virtual ground points "a, b" in coil #1 to "c, d" in coil #2. However, the shorting between points "a, c" is done with two turns, the first turn exists in the virtual ground plane of coil #1 and the second turn in the virtual ground plane of coil #2. This is done such that coils #1 and #2 will not see coil #3. Also, this shorting is interrupted with C2 and the shorting between the points "b, d" is interrupted with C3 value capacitor. Please note, only two turns are used for coils #1 and #2, for simplicity. In practice, coils #1 and #2 may have N (N.gtoreq.1) turns, and coil#3 may have M (M=N or M.noteq.N) turns.

Detailed Description Text (57):
The resultant integrated structure I comprises of coils #1 and #2 that are overlapped for minimum mutual inductance and coil #3 physically connecting coils #1 and #2, such that there is no net coupling between coils #1 and #2 via coil #3. In this preferred case for human imaging, all coils are tuned to the same NMR frequency. However for the NQR case, all coils may be tuned to the same or different frequencies.

Detailed Description Text (58):
A preferred embodiment is where all coils are tuned to different NQR frequencies and have their own tunable range of frequencies, lets say for example coil #1 covers from 0.5-1.5 MHz, coil #2 from 1.5-3.0 MHz and coil #3 from 3-5 MHz, respectively. Each coil design is optimized to cover this frequency range and has its own capacitor bank as shown in FIG. 13b to tune the specified frequency range. The individual switches may be computer controlled (not shown) to tune the individual RF coil to the specified resonance frequencies. The object that need to be scanned is introduced along the coil axis.

Detailed Description Text (59):
Alternately, the solenoid design may be adapted to a surface type design and may be used for surface detection of drugs, narcotics, explosives, etc. The RF coil may also be used in a quasi surface--volume type design as well, for several medical and non-medical applications.

Detailed Description Text (60):
FIG. 14 is a system block diagram, which illustrates the utility of the RF coil of the pressent invention in NMR imaging and spectroscopy, for example. The system has a main magnet which covers the time varying gradient coils, an RF shield that isolates the RF coil from the gradient coils and a whole-body RF coil most commonly used for uniform B field transmit over a large imaging FOV. The main magnet strength sets the NMR frequency of operation. The time varying gradient fields help spatially encode the NMR signals. The RF whole body coil is used to transmit, while the local RF coil is used to pick up the NMR signals from the object under investigation (NMR phantom). A number of receiver coils may be used in an array configuration and may be summed either analog or digitally to produce the resultant image. Signals from the several receiver ports may be acquired via one or multiple receiver channels. An n-to-1 channel multiplexer is shown in the drawing. This helps by -pass n channel coil data to use one channel of the NMR system. Alternatively, an n channel NMR system may also be used.

Detailed Description Text (62):
From all the above description, for someone skilled in the art, is must now be apparent that the inventive novel concept of FIG. 7 may be adapted to a number of different coil designs for the several resonance techniques, such as NMR, NQR, etc. It must also now be apparent that the individual coils in an integrated RF coil system may be tuned to the same or different frequencies.

Detailed Description Text (63):
It is to be noted that the individual coils in the array may be shaped in such a way to provide a high S/N and uniform coverage over the imaging FOV. The coils may be used to image in the different operating modes. The signal may be combined prior to the preamplifier or post the preamplifier in analog or digital fashion. The

individual coils in the array may be tuned to one or more frequencies.

Detailed Description Text (64):
It must be further apparent that the coil designs in the distributed cases may be of the low-pass, high-pass, band-pass, band-stop or a combination of the above different configurations. Also, the coils may be of the volume type, surface type or a combination of both. Individual coils in the array may be linear or in quadrature. The coils may be used for transmit only, receive only or may be used for transmit and receive purposes. Individual coils in the array may be interfaced to separate channels in the multi-channel resonance system or may be time-multiplexed to one or more channels of a single or multi-channel resonance system.

Other Reference Publication (1):
Ravi Srinivasan and Haiying Liu, A Comprehensive Analysis for Estimating Modes in Coupled Resonators, p. 1425.

Other Reference Publication (2):
Michael Burl, Ian R, Young, Examples of the Design of Screened and Shielded RF Receiver Coils, pp. 326-330.

Other Reference Publication (3):
Srinivasan, Improved Radio-Frequency Coil and M Ethod for Resonance/Imaging Analysis, U.S. Patent Application No. 08/993,932, filed Dec. 18, 1997.

Other Reference Publication (5):
"Optimized Birdcage Resonators for Simultaneous MRI of Head and Neck" by C. Leussler SMR 1993.

Other Reference Publication (6):
"A Comprehensive Analysis for Estimating Modes in Coupled Resonators"; by Ravi Srinivasan and Haiying Liu.

Other Reference Publication (7):
"Examples of the Design of Screened and Shielded RF Receiver Coils"; Michael Burl and Ian R. Young, pp. 326-330.

CLAIMS:

1. A radio-frequency (RF) coil array for resonance imaging/analysis, comprising:

a first RF coil sensitive to RF signals produced during resonance imaging/analysis;

a second RF coil located relative to the first RF coil with substantially no net coupling therebetween at a frequency or frequencies of the RF signals; and

a third RF coil electrically connected and located relative to the first RF coil and the second RF coil such that there is substantially zero net current flow between the first RF coil and the second RF coil via the third RF coil, each of the first RF coil, second RF coil and third RF coil being substantially isolated from the other coils at the frequency or frequencies of the RF signals.

2. The coil array of claim 1, wherein the first RF coil, second RF coil and third RF coil are sufficiently isolated from one another to maintain predefined current distributions and mode orientations for the respective coils.

3. The coil array of claim 1, wherein the third RF coil has a field-of-view which is similar as compared to a combined field-of-view of the first RF coil and the second RF coil.

4. The coil array of claim 1, wherein each of the first RF coil, second RF coil and third RF coil are volume type coils.

5. The coil array of claim 4, wherein each of the first RF coil, second RF coil and third RF coil are birdcage type coils.

6. The coil array of claim 5, wherein the coil array is sized to receive at least one of a human head, a human knee, and a human wrist within the first RF coil second RF coil and third RF coil.

7. The coil array of claim 5, further comprising a fourth RF coil positioned toward an end of the coil array.

8. The coil array of claim 5, wherein the coil array is sized to receive a human head.

9. The coil array of claim 5, wherein the coil array is sized to receive a human head and neck.

10. The coil array of claim 4, wherein each of the first RF coil, second RF coil and third RF coil are solenoid type coils.

11. The coil array of claim 10, wherein the coil array is sized to receive at least one of a human head, knee, wrist or torso within the first RF coil, second RF coil and third RF coil.

12. The coil array of claim 1, wherein each of the first RF coil, second RF coil and third RF coil are surface type coils.

13. The coil array of claim 12, further comprising a fourth RF coil.

14. The coil array of claim 1, wherein the net shared magnetic flux between the first RF coil and the second RF coil is substantially zero.

15. The coil array of claim 1, wherein the third RF coil is physically connected to the first RF coil and the second RF coil.

16. The coil array of claim 1, wherein the first RF coil and the second RF coil maintain substantially similar physical dimensions.

17. The coil array of claim 1, wherein each of the first RF coil, second RF coil and third RF coil is configured to provide a quadrature output.

18. The coil array of claim 1, further comprising means for selectively turning the first RF coil, second RF coil and third RF coil on and off to control a mode of operation.

19. The coil array of claim 1, wherein at least one of the first RF coil, second RF coil and third RF coil is a volume type coil, and at least another of the first RF coil, second RF coil and third RF coil is a surface type coil.

20. The coil array of claim 1, wherein the first RF coil, second RF coil and third RF coil are tuned to the same resonance frequency.

21. The coil array of claim 1, wherein the first RF coil and the second RF coil are tuned to one resonance frequency, and the third RF coil is tuned to another resonance frequency.

22. The coil array of claim 1, wherein the first RF coil, second RF coil and third RF coil are tuned to respective different resonance frequencies.

23. A system comprising the coil array of claim 1, and further comprising means for driving the coil array during imaging/analysis.

24. A resonance imaging/analysis system, comprising:

an RF coil as recited in claim 1; and

means for processing RF signals which are at least one of received from the RF coil and transmitted from the RF coil in order to obtain a resonance image/analysis.

25. The coil array of claim 1, wherein the isolation between the first and second RF coils is substantially the same with the third RF coil as without the third RF coil.

26. A radio-frequency (RF) coil array for resonance imaging/analysis, comprising:

a first RF coil sensitive to RF signals produced during resonance imaging/analysis;

a second RF coil located relative to the first RF coil with substantially no net coupling therebetween at a frequency or frequencies of the RF signals; and

a third RF coil electrically connected and located relative to the first RF coil and the second RF coil such that there is substantially no net coupling between the first RF coil and the second RF coil via the third RF coil, each of the first RF coil, second RF coil and third RF coil being substantially isolated from the other coils at the frequency or frequencies of the RF signals.

27. The coil array of claim 26, wherein the isolation between the first and second RF coils is substantially the same with the third RF coil as without the third RF coil.

28. A radio-frequency (RF) coil array for resonance imaging/analysis, comprising:

a first RF coil sensitive to RF signals produced during resonance imaging/analysis;

a second RF coil located relative to the first RF coil with substantially no net coupling therebetween at a frequency or frequencies of the RF signals; and

a third RF coil located relative to the first RF coil and the second RF coil such that each of the first RF coil, second RF coil and third RF coil are substantially isolated from the other coils at the frequency or frequencies of the RF signals;

wherein a field-of-view of the third RF coil substantially overlaps and is substantially similar to a combined field-of-view of the first and second RF coils.

29. The coil array of claim 28, wherein the third RF coil is electrically connected to the first RF coil and the second RF coil.

30. The coil array of claim 28, wherein

the third RF coil is electrically connected to the first and second RF coils, and

the isolation between the first and second RF coils is substantially the same with the third RF coil as without the third RF coil.

31. The coil array of claim 30, wherein the third RF coil is electrically connected to the first RF coil and the second RF coil.

32. A radio-frequency (RF) coil array for resonance imaging/analysis, comprising:

a first RF coil sensitive to RF signals produced during resonance imaging/analysis;

a second RF coil located relative to the first RF coil with substantially no net coupling therebetween at a frequency or frequencies of the RF signals; and

a third RF coil located relative to the first RF coil and the second RF coil such that there is substantially no net coupling between the first RF coil and the second RF coil via the third RF coil, each of the first RF coil, second RF coil and third RF coil being substantially isolated from the other coils at the frequency or frequencies of the RF signals;

wherein a field-of-view of the third RF coil substantially overlaps and is substantially similar or larger than a combined field-of-view of the first and second RF coils.

33. The coil array of claim 32, wherein

the third RF coil is electrically connected to the first and second RF coils, and

the isolation between the first and second RF coils is substantially the same with the third RF coil as without the third RF coil.